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SCATTERING DISPLAY ELEMENT AND METHOD FOR DRIVING THE SAME

TECHNICAL FIELD

The present invention relates to scattering display elements displaying an image by scattering or transmitting incident light, which can be used in portable information terminals or portable gaming devices, and in particular to reflective scattering liquid crystal display elements having a polymer–dispersed liquid crystal layer and taking external light as the main light source, as well as to manufacturing methods for such display elements.

BACKGROUND ART

Conventionally, twisted nematic (TN) liquid crystal display elements are widely used. Such display elements are provided with a liquid crystal layer and a polarizer, and images are displayed by changing the polarization of light through the liquid crystal layer and controlling the light transmitted through the polarizer. Therefore, only the light components matching the polarization axis of the polarizer are transmitted, even during bright (white) display, and reflective liquid crystal display elements provided with a reflector and taking external light as the light source in particular are deficient in that it is difficult to attain a bright display. In order to improve this deficiency, display elements are known, in which a large amount of the reflected external light is directed toward the main observation direction (viewing direction), as disclosed for example in JP S61–270731A, JP

H07–181481A, JP H09–80426A, and JP H10–232395A. More specifically, a large amount of light that is incident from obliquely above the display screen is directed in forward direction (viewing direction) for example by providing a reflector 211 with protrusions 211a formed as lateral stripes, as shown in Fig. 64, or segments or circles, by providing the cross–section of a reflector 212 with sawtooth shape, as shown in Fig. 65, or by roughening the reflection surface. However, even when using such reflectors, light is still absorbed by the polarizer, and it is difficult to increase the luminance substantially.

On the other hand, scattering liquid crystal display elements, such as polymer–network liquid crystal display elements or polymer–dispersed liquid crystal display elements, have been developed in recent years as display elements without polarizers. As shown for example in "Flat Panel Display '91" (published by Nikkei BP, p.221) or "S. Shikama et. al., Society for Information Display '95, pp. 231–234" this kind of display element has a compound layer of a polymer and a liquid crystal provided between a pair of substrates. Electrodes are provided on the two substrates, and depending on whether voltage is applied to these electrodes, the compound layer is switched between an optically scattering state and a transmitting state. As in the examples of the direct–vision display disclosed for example in JP H07–104250A and JP H08–43849A, a black body is provided on the rear side of the substrate pair, and dark (black) display is achieved when the compound layer is in the transparent state and incident external light is transmitted through the compound layer and absorbed by the black body,

whereas bright display is achieved when the compound layer is in the scattering state and incident external light is scattered, so that the display appears cloudy from any direction. This means that a display with a relatively high luminance is attained, because during bright display, light that is scattered towards the display side of the display element enters the visual field without being absorbed by a polarizer. Furthermore, JP H09-90352A discloses that the contrast can be increased by adhering a reflective film only on the oblique faces of triangular prism-shaped protrusions having 42° to 70° oblique faces, and deviating incident light toward the rear face of the reflector during dark display.

In order to increase the luminance even further, a scattering display element using a technique called IRIS (Internal Reflection Inverted Scattering) has been proposed as described in SID Digest (published by The Society for Information Display; 1997: p.1023; 1998: p. 758 – 761). As shown in Fig. 66(a), this display element is provided with a reflector 214, instead of the black body, on the rear side of the compound layer 213, so that light that is scattered toward the rear side of the compound layer 213 is reflected by the reflector 214 and directed toward the front side, which leads to a display with higher luminance. The surface of the reflector 214 is mirror finished. It seems also possible to provide the reflector with protrusions and recesses that are isotropic with respect to the vertical and the horizontal directions of the display screen.

However, in such scattering liquid crystal display elements, there is the problem that it is difficult to display images with high luminance and

high contrast yet without gray-scale inversion when attempting to increase the luminance by increasing the scattering degree during the scattering state while increasing the transmissivity during the transmitting state. In order to overcome this problem, a display using a reverse–mode polymer–dispersed layer has been suggested, in which the reflector is mirror finished, and a liquid crystal and a birefringent polymer are arranged with respect to one another inside the panel, as disclosed for example in JP H07–4950A. However, in this display element, the fraction of the liquid crystal is relatively large, so that the network structure of the polymer is weak, and there is the problem that display deficiencies, such as hysteresis, occur easily.

Moreover, in scattering display elements, a reduction in contrast and gray-scale inversion also tend to occur due to so–called external light reflection. More specifically, although the luminance during bright display of a scattering display element provided with a reflector 214 as described above is high, depending on the direction from which the displayed image is viewed, reflected external light enters the visual field during dark display, and there is the problem that the gradation of the displayed image reverses. This means that since the compound layer 213 becomes transmissive during dark display, external light that is incident on the compound layer 213 is transmitted by the compound layer 213 as is, and after it is reflected by the reflector 214, it is again transmitted by the compound layer 213 and emitted, as shown in Fig. 66(b). Therefore, when viewing roughly from the direction

indicated by the arrow A in Fig. 66(b), the reflected external light enters the visual field, and the display seems to be brighter than during bright display, so that gray-scale inversion occurs. However, when viewing from other directions (for example, from the direction indicated by the arrow B), the reflected external light does not enter the visual field, so that a suitable dark display is attained.

Referring to Fig. 68, the following is a more detailed explanation of the relation between the incidence direction of external light and the direction from which the image is viewed, when using a display element 215 in oblique orientation as show in Fig. 67 for example. Fig. 68 charts the directions from which external light is incident, and the direction with respect to the origin O (for example, arrow M in Fig. 68) represents the incidence direction in which light is projected onto the display screen, whereas the distance from the origin O (for example, angle L or distance L in Fig. 68) represents the angle between the incidence direction and the normal on the display screen. As shown in Fig. 68, in many cases, external light (light–source light) is irradiated from a direction indicated by the position P in Fig. 68 (that is, obliquely from the front of the display screen), and the displayed image is viewed from a direction indicated by the region Q (that is, a direction that widens horizontally with respect to a direction perpendicular to the display screen). On the other hand, the reflected external light is emitted into a direction indicated by the position R, which is symmetric to the position P with respect to the origin O. Thus, the reflected external light enters the visual field when viewing from a certain portion of the

viewing range or from a region slightly beyond the region Q, leading to gray-scale inversion.

As technique for reducing the afore–mentioned deficiencies, it has been suggested to provide a diffraction grating film on the surface side of the compound layer, as described for example in "International Display Research Conference 1997" (published by The Society for Information Display, p. 255). That is to say, external light is scattered (blurred) to some degree by the diffraction grating film, and its brightness is reduced, whereby the influence of the reflected light can be alleviated.

However, if the amount of reflected external light is large, gray-scale inversion and a reduction in contrast still occurs even when such a diffraction grating film is provided, and it is difficult to prevent this entirely.

Furthermore, when the external light is blurred, the region in which it enters the visual field widens up, as indicated by the region R' in Fig. 68, so that the reduction in contrast tends to occur over a wider viewing range.

Moreover, it seems possible to make for example the reflector scattering, so as to scatter the external light somewhat as described above, but it is relatively difficult to manufacture such a reflector, as it requires extremely precisely machined dies, which will drive up the manufacturing costs.

Furthermore, the inventors found that in conventional scattering liquid crystal display elements, reductions in luminance and contrast as well as gray-scale inversion are also caused by the driving conditions for the liquid crystal display element. That is to say, in the above–described

conventional examples, there are the problems that a bright display cannot be attained, because the brightness is determined by the initial scattering state, and that gray-scale inversion occurs when displaying intermediate gradations. The results of experiments carried out by the inventors show that in scattering liquid crystal display devices, these are not fundamental problems, but are rather rooted in a misunderstanding regarding the luminance – voltage characteristics. That is, taking the case of normally–white displays as an example, in this case the luminance – voltage characteristics have conventionally been assumed to be generally such that the luminance is at the highest level when no voltage is applied, the highest level is maintained from an applied voltage of 0V to a region where the voltage is slightly increased, and above this voltage, the luminance level decreases sharply, until it reaches approximately zero, as shown in Fig. 69. However, as experiments carried out by the inventors show, the actual voltage – luminance characteristics are not as shown in Fig. 69, but there is a value for the applied voltage at which the luminance level peaks, as shown in Fig. 51. Therefore, it seems that in conventional scattering–mode liquid crystal display devices, display is carried out on the basis of voltage – luminance characteristics that are different from the actual voltage – luminance characteristics, so that a sufficient luminance is not attained, and gray-scale inversion occurs. Thus, the inventors succeeded in inventing a liquid crystal display device solving the above–mentioned problems by carrying out the display on the basis of the voltage – luminance characteristics shown in Fig. 51.

DISCLOSURE OF THE INVENTION

With the foregoing in mind, it is an object of the present invention to provide a scattering display element with excellent viewability, in which the luminance is increased during bright display and reduced during dark display, and the effect of reflected external light is eliminated or greatly reduced, which has high luminance, and in which gray-scale inversion and reduction in contrast occurs less easily, as well as a method for manufacturing such a scattering display element, with which the manufacturing costs can be reduced.

In order to achieve this object, the inventors have researched the subject in depth, and as a result of this research, have found that there is a peak in the voltage – reflectivity characteristics of normally–white–mode reflective polymer–dispersed liquid crystal display elements (see Fig. 3). Consequently, higher luminance and higher contrast can be achieved by taking this peak as the white luminance.

Furthermore, the inventors found that this peak value is correlated with the scattering gain of the polymer–dispersed liquid crystal layer, and that there is a range of optimum scattering gains to achieve an even larger peak value (see Fig. 5). Furthermore, the scattering gain depends on the panel gap, the particle diameter of the liquid crystal drops, and the level of the refractive index anisotropy of the liquid crystal, so that there are also optimum values for the panel gap, the particle diameter of the liquid crystal

drops, and the level of the refractive index anisotropy of the liquid crystal. Thus, values for the panel gap, the particle diameter of the liquid crystal drops, and the level of the refractive index anisotropy of the liquid crystal were determined, at which optimum scattering gains are achieved.

The present invention was conceived on the basis of the foregoing effects and facts. Specific configurations of the present invention are as follows:

A reflective liquid crystal display element in accordance with Claim 1 comprises:

a pair of substrates;

a polymer–dispersed liquid crystal layer, in which liquid crystal drops are dispersed in a polymer, the polymer–dispersed liquid crystal layer being arranged between the pair of substrates; and

a reflective layer formed on one substrate of the pair of substrates;

wherein display is carried out by applying an electric field across the polymer–dispersed liquid crystal layer to change a light–scattering state of the polymer–dispersed liquid crystal layer; and

wherein the scattering gain of the polymer–dispersed liquid crystal layer is set in accordance with the thickness of the polymer–dispersed liquid crystal layer.

In accordance with Claim 2, the scattering gain is the scattering gain for transmitted light when the polymer–dispersed liquid crystal layer is formed in a transmissive panel.

In accordance with Claim 3, the thickness d of the polymer–dispersed liquid crystal layer is at least 3μm and at most 8μm.

In accordance with Claim 4, the particle diameter of the liquid crystal drops in the polymer–dispersed liquid crystal layer is set in accordance with the thickness of the polymer–dispersed liquid crystal layer.

A reflective liquid crystal display element in accordance with Claim 5 comprises:

a pair of substrates;

a polymer–dispersed liquid crystal layer, in which liquid crystal drops are dispersed in a polymer, the polymer–dispersed liquid crystal layer being arranged between the pair of substrates; and

a reflective layer formed on one substrate of the pair of substrates;

wherein display is carried out by applying an electric field across the polymer–dispersed liquid crystal layer to change a light–scattering state of the polymer–dispersed liquid crystal layer; and

wherein the scattering gain of the polymer–dispersed liquid crystal layer is set in accordance with the level of refractive index anisotropy of the liquid crystal included in the polymer–dispersed liquid crystal layer.

In accordance with Claim 6, the particle diameter of the liquid crystal drops in the polymer–dispersed liquid crystal layer is set in accordance with the level of refractive index anisotropy of the liquid crystal.

A reflective liquid crystal display element in accordance with Claim 7 comprises:

a pair of substrates;

a polymer–dispersed liquid crystal layer, in which liquid crystal drops are dispersed in a polymer, the polymer–dispersed liquid crystal layer being arranged between the pair of substrates; and

a reflective layer formed on one substrate of the pair of substrates;

wherein display is carried out by applying an electric field across the polymer–dispersed liquid crystal layer to change a light–scattering state of the polymer–dispersed liquid crystal layer; and

wherein the scattering gain of the polymer–dispersed liquid crystal layer is set in accordance with the thickness of the polymer–dispersed liquid crystal layer and the level of refractive index anisotropy of the liquid crystal included in the polymer–dispersed liquid crystal layer.

A reflective liquid crystal display element in accordance with Claim 8 comprises:

a pair of substrates;

a polymer–dispersed liquid crystal layer, in which liquid crystal drops are dispersed in a polymer, the polymer–dispersed liquid crystal layer being arranged between the pair of substrates; and

a reflective layer formed on one substrate of the pair of substrates;

wherein display is carried out by applying an electric field across the polymer–dispersed liquid crystal layer to change a light–scattering state of the polymer–dispersed liquid crystal layer; and

satisfying the relation $50\exp(-0.4d) < SG < 360\exp(-0.47d)$, wherein d is the thickness of the polymer–dispersed liquid crystal layer and SG is the scattering gain of the polymer–dispersed liquid crystal layer.

In accordance with Claim 9, the scattering gain is the scattering gain for transmitted light when the polymer–dispersed liquid crystal layer is formed in a transmissive panel.

In accordance with Claim 10, the thickness d of the polymer–dispersed liquid crystal layer is at least 3μm and at most 8μm.

In accordance with Claim 11, the scattering gain of the liquid crystal layer is at least 10 and at most 200.

In accordance with Claim 12, the scattering gain of the liquid crystal layer is at least 10 and at most 200 within a usage temperature range of the liquid crystal display device.

A reflective liquid crystal display element in accordance with Claim 13 comprises:

a pair of substrates;

a polymer–dispersed liquid crystal layer, in which liquid crystal drops are dispersed in a polymer, the polymer–dispersed liquid crystal layer being arranged between the pair of substrates; and

a reflective layer formed on one substrate of the pair of substrates;

wherein display is carried out by applying an electric field across the polymer–dispersed liquid crystal layer to change a light–scattering state of the polymer–dispersed liquid crystal layer; and

satisfying the relation $50\exp(-1.6\Delta n \cdot d) < SG < 360\exp(-1.88\Delta n \cdot d)$, wherein d(μm) is the thickness of the polymer–dispersed liquid crystal layer and SG is the scattering gain of the polymer–dispersed liquid crystal layer.

In accordance with Claim 14, the scattering gain is the scattering

gain for transmitted light when the polymer–dispersed liquid crystal layer is formed in a transmissive panel.

In accordance with Claim 15, the thickness d of the polymer–dispersed liquid crystal layer is at least 3μm and at most 8μm.

In accordance with Claim 16, the scattering gain of the liquid crystal layer is at least 10 and at most 200.

In accordance with Claim 17, the scattering gain of the liquid crystal layer is at least 10 and at most 200 within a usage temperature range of the liquid crystal display device.

The relation between the scattering gain and the contrast is as shown in Fig. 5. As becomes clear from Fig. 5, for each thickness d of the polymer–dispersed liquid crystal layer (corresponding to the panel gap) there is a scattering gain at which the contrast becomes largest. Taking a range of at least 70% of this largest contrast in Fig. 5, the relation between the panel gap d and the scattering gain is as shown in Fig. 6. The line P1 in Fig 6 marks the upper limit of the tolerance range for the scattering gain, and line P3 in Fig 6 marks the lower limit of the tolerance range for the scattering gain. Consequently, a contrast of at least 70% of the maximum contrast can be attained if the scattering gain is set within the range defined by the lines P1 and P3. Here, the line P1 is given by SG = 360exp(–0.47d), and the line P3 is given by SG = 50exp(–0.4d). Therefore, a contrast of at least 70% of the maximum contrast can be attained and a reflective polymer–dispersed liquid crystal display element is achieved, if the

scattering gain SG in the polymer–dispersed liquid crystal layer satisfies $50\exp(-0.4d) < SG < 360\exp(-0.47d)$.

Here, the “reflective layer” can be a reflective pixel electrode made of a reflective metal serving as both reflective layer and electrode, but it is also possible to use a transparent electrode as a pixel electrode, and to form the reflective layer separately on the substrate.

Furthermore, the thickness d of the polymer–dispersed liquid crystal layer is restricted due to the following reasons. When the thickness d is less than 3μm, then it is difficult to actually make it uniform, and when the thickness d is larger than 8μm, then the driving voltage becomes too large.

A reflective liquid crystal display element in accordance with Claim 18 comprises:

a pair of substrates;

a polymer–dispersed liquid crystal layer, in which liquid crystal drops are dispersed in a polymer, the polymer–dispersed liquid crystal layer being arranged between the pair of substrates;

a reflective layer formed on one substrate of the pair of substrates;

wherein display is carried out by applying an electric field across the polymer–dispersed liquid crystal layer to change a light–scattering state of the polymer–dispersed liquid crystal layer; and

wherein the product of the birefringence of the liquid crystal and the thickness of the polymer–dispersed liquid crystal layer is at least 0.6μm and at most 2.2μm.

The scattering gain depends, among others, on the thickness d of the polymer–dispersed liquid crystal layer, the birefringence Δn of the liquid crystal, and the particle size of the liquid crystal drops. The inventors experimentally observed that the relation between Δnd and the contrast is as shown in Fig. 8. In Fig. 8, it can be ascertained that the product Δnd corresponding to a contrast of at least 30 is in a range at least 0.6μm and at most 2.2μm. Since the contrast of conventional reflective polymer–dispersed liquid crystal display elements is only about 10, a much higher contrast than in the conventional examples can be attained by setting the contrast higher to 30 or higher.

In accordance with Claim 19, the particle diameter of the liquid crystal drops is at least 0.7μm and at most 2μm.

In accordance with 20, the birefringence of the liquid crystal is at least 0.15μm and at most 0.27μm.

In accordance with Claim 21, wherein the thickness of the polymer–dispersed liquid crystal layer is at least 3μm and at most 8μm.

A reflective liquid crystal display element in accordance with Claim 22 comprises:

a pair of substrates;

a polymer–dispersed liquid crystal layer, in which liquid crystal drops are dispersed in a polymer, the polymer–dispersed liquid crystal layer being arranged between the pair of substrates;

a reflective layer formed on one substrate of the pair of substrates;

wherein display is carried out by applying an electric field across the polymer–dispersed liquid crystal layer to change a light–scattering state of the polymer–dispersed liquid crystal layer;

wherein the liquid crystal drops near the border of the substrates are formed substantially as semi–spheres whose great circles contact the substrates; and

wherein directors of the liquid crystal inside the semi–spherical liquid crystal drops are arranged substantially uniformly in parallel to the substrates.

The directors of the liquid crystal molecules in the liquid crystal drops at the substrate borders are arranged approximately in parallel to the substrates, which lowers the scattering at the border layer and increases the scattering gain. Consequently, the scattering gain can be adjusted to a suitable value by adjusting the size of the semi–spheres. This means that it is possible to adjust the scattering gain of the panel to a suitable range without changing the liquid crystal composition or the particle diameter of the liquid crystal drops, by orienting the liquid crystal at the substrate borders into the same direction.

In accordance with Claim 23, the directors of the liquid crystal inside the semi–spherical liquid crystal drops at the border of one of the pair of substrates and the directors of the liquid crystal inside the liquid crystal

drops at the border of the other of the pair of substrates are substantially parallel.

With this configuration, the scattering gain at the borders of the substrate pair can be reduced even further.

In accordance with Claim 24, the thickness of the polymer–dispersed liquid crystal layer is at least 3μm and at most 8μm.

The thickness of the polymer–dispersed liquid crystal layer is restricted for the same reasons as explained for Claim 3.

A reflective liquid crystal display element in accordance with Claim 25 comprises:

a pair of substrates;

a polymer–dispersed liquid crystal layer, in which liquid crystal drops are dispersed in a polymer, the polymer–dispersed liquid crystal layer being arranged between the pair of substrates;

a reflective layer formed on one substrate of the pair of substrates; and

an RGB color filter formed on one of the substrates;

wherein display is carried out by applying an electric field across the polymer–dispersed liquid crystal layer to change a light–scattering state of the polymer–dispersed liquid crystal layer;

wherein, when d(μm) is the thickness of polymer–dispersed liquid crystal layer, and, among the scattering gains for green light in the polymer–dispersed liquid crystal layer, SGr is the scattering gain of a red pixel region, SGg is the scattering gain of a green pixel region, and SGb is the scattering gain of a blue pixel region, then

$50\exp(-0.4d) < SGg < 360\exp(-0.47d)$ is satisfied in the green pixel region;

$50\exp(-0.4d) < SGb < 360\exp(-0.47d)$ is satisfied in the blue pixel region; and

$40\exp(-0.3d) < SGr < 650\exp(-0.4d)$ is satisfied in the red pixel region.

When an RGB color filter is used, full color display becomes possible. In this situation, the scattering properties of the polymer–dispersed liquid crystal layer differ depending on the RGB wavelengths, so that the suitable range of the scattering gains has to be considered individually for R, G and B. We have found experimentally that, when d(μm) is the thickness of polymer–dispersed liquid crystal layer, and, among the scattering gains for green light in the polymer–dispersed liquid crystal layer, SGr is the scattering gain of a red pixel region, SGg is the scattering gain of a green pixel region, and SGb is the scattering gain of a blue pixel region, then contrast can be increased if SGr, SGg and SGb are set within the ranges mentioned above. It should be noted that the reasons why setting SGr, SGg and SGb within the above–mentioned ranges leads to a larger contrast are

substantially the same reasons as explained for Claim 1.

In accordance with Claim 26, dR > dG > dB is satisfied, wherein dR is a layer thickness of the red pixel region, dG is a layer thickness of the green pixel region, and dB is a layer thickness of the blue pixel region.

With this configuration, the liquid crystal display element is easy to manufacture.

In accordance with Claim 27, rR > rG > rB is satisfied, wherein rR is a particle diameter of the crystal drops in the red pixel region, rG is a particle diameter of the crystal drops in the green pixel region, and rB is a particle diameter of the crystal drops in the blue pixel region.

With this configuration, a substantially uniform display contrast is attained for each of the RGB pixels, in addition to a display with high contrast.

In accordance with Claim 28, the color filter is formed on the reflective layer, and the polymer–dispersed liquid crystal layer is formed on the color filter.

In accordance with Claim 29,

when viewed from a predetermined viewing direction, there is a luminance peak in the luminance – voltage characteristics as the liquid

crystal layer is changed from the scattering state to the transmitting state; and

a range between a voltage at the luminance peak in the voltage – luminance characteristics and a voltage at which the luminance becomes approximately zero is taken as a driving voltage range.

In accordance with Claim 30,

when viewed from a predetermined viewing direction, there is a luminance peak in the luminance – voltage characteristics as the liquid crystal layer is changed from the scattering state to the transmitting state; and

a range between a voltage at the luminance peak in the voltage – luminance characteristics and a voltage at which the luminance becomes approximately zero is taken as a driving voltage range.

In accordance with Claim 31, said viewing direction is set to a direction that is different from an emission direction, in which light is emitted frontwards from the liquid crystal layer when the liquid crystal layer is in the transmitting state.

In accordance with Claim 32, said viewing direction is set to a direction that is different from an emission direction, in which light is emitted frontwards from the liquid crystal layer when the liquid crystal layer is in the transmitting state.

Also, to attain the afore–mentioned objects, a scattering display element in accordance with Claim 33 comprises:

a scattering/transmission means switching between a scattering state, in which incident light is scattered, and a transmitting state, in which incident light is transmitted;

a reflection means for reflecting light that is incident from a display side of the scattering/transmission means and scattered on a rear side, as well as light that is transmitted by the scattering/transmission means; and

an anisotropic scattering means, which, when the scattering/transmission means is in the transmitting state, scatters and emits light, that is incident on the scattering display element, into a range of directions with anisotropy.

According to Claim 34, in the scattering display element of Claim 33, the anisotropic scattering means scatters and emits light, that is incident on the scattering display element, into a range of directions that is broader in a horizontal direction of a display screen than in a vertical direction of the display screen.

According to Claim 35, in the scattering display element of Claim 33, the reflection means is part of the anisotropic scattering means.

According to Claim 36, in the scattering display element of Claim 35, the anisotropic scattering means is made by forming protrusions whose curvature in a horizontal direction of the display screen is larger than the curvature in a vertical direction of the display screen on a surface of the reflection means.

According to Claim 37, in the scattering display element of Claim 33, the anisotropic scattering means includes an anisotropic transmission means,

which scatters and transmits incident light into a range of directions with anisotropy.

According to Claim 38, in the scattering display element of Claim 37, protrusions whose curvature in a horizontal direction of the display screen is larger than the curvature in a vertical direction of the display screen are formed on a surface of the anisotropic transmission means.

According to Claim 39, in the scattering display element of Claim 38, the anisotropic transmission means is a lens sheet film.

According to Claim 40, in the scattering display element of Claim 33, the anisotropic scattering means is an anisotropic diffraction means.

In this manner, by providing an anisotropic transmission means or a reflection means, such as a reflector or a sheet film, with anisotropic scattering, light that is incident on the scattering display element is scattered into directions over an anisotropic range, such as a range that is wider in horizontal direction than in vertical direction with respect to the display screen, so that the reflection properties of external light can be optimized, the luminance of reflected light can be reduced, and, by emitting into a direction that in which light enters the visual field less easily, the influence of reflected external light, such as luminance inversion and lower contrast, can be eliminated or at least greatly reduced.

A scattering display element in accordance with Claim 41 comprises: a scattering/transmission means for switching between a scattering

state, in which incident light is scattered, and a transmitting state, in which incident light is transmitted;

a reflection means for reflecting light that is incident from a display side of the scattering/transmission means and scattered on a rear side, as well as light that is transmitted by the scattering/transmission means; and

an emission angle modification means, which, when the scattering/transmission means is in the transmitting state, emits light, that is incident on the scattering display element, into a direction such that the incidence angle is different from the emission angle.

According to Claim 42, in the scattering display element of Claim 41, the emission angle modification means is configured such that the emission angle is larger than the incidence angle.

According to Claim 43, in the scattering display element of Claim 42, the reflection means is part of the emission angle modification means.

According to Claim 44, in the scattering display element of Claim 43, the emission angle modification means is made by providing the reflection means with regions, in which a normal on a reflection surface is tilted downward with respect to the display screen against a normal on a display surface.

According to Claim 45, in the scattering display element of Claim 44, a cross–section of the reflection means in vertical direction of the display screen is provided with a shape having sawtooth–shaped portions.

According to Claim 46, in the scattering display element of Claim 45, an inclination angle, with respect to the display surface, of an inclined

surface in the cross–sectional shape having sawtooth–shaped portions is at least 5° and at most 30°.

According to Claim 47, in the scattering display element of Claim 46, an inclination angle with respect to the display surface of an inclined surface in the cross–section having sawtooth–shaped portions is at least 5° and at most 15°.

According to Claim 48, the scattering display element of Claim 45 is provided with a plurality of the cross–sectional shapes having sawtooth–shaped portions, wherein a pitch between the cross–sectional shapes is set to at least 5μm and at most 100μm.

According to Claim 49, the scattering display element of Claim 45 is provided with a plurality of the cross–sectional shapes having sawtooth–shaped portions, wherein pitches between the cross–sectional shapes are set to a plurality of varying sizes.

According to Claim 50, in the scattering display element of Claim 49, the pitches of varying sizes are arranged at random.

According to Claim 51, the scattering display element of Claim 45 is provided with a plurality of the cross–sectional shapes having sawtooth–shaped portions, wherein pitches between the cross–sectional shapes are set to at least 5μm and at most 100μm, and the difference between the largest pitch and the smallest pitch is set to be not larger than 30μm.

According to Claim 52, in the scattering display element of Claim 43, in a cross–section of the reflection means in a vertical direction of the

display screen, a normal on a reflection surface is tilted downward with respect to the display screen against a normal on a display surface; and

the reflection means is provided with a plurality of protrusions whose cross–sectional shape protrudes in a horizontal direction of the display screen are formed.

According to Claim 53, in the scattering display element of Claim 52, the protrusions are arranged at random positions.

According to Claim 54, in the scattering display element of Claim 42, the emission angle modification means includes a refraction/transmission means for refracting and transmitting incident light.

According to Claim 55, in the scattering display element of Claim 54, the refraction/transmission means is provided with a region that is thicker at a higher position of the display screen than at a lower position of the display screen.

According to Claim 56, in the scattering display element of Claim 55, a cross–section of the refraction/transmission means in vertical direction of the display screen is provided with a shape of a plurality of half convex lenses or prisms.

According to Claim 57, in the scattering display element of Claim 41, the emission angle modification means is configured such that light that is incident on the scattering display element is emitted substantially in a direction back toward the direction of incidence.

According to Claim 58, in the scattering display element of Claim 57, the emission angle modification means is configured by providing the

reflection means with retroreflector shape.

According to Claim 59, in the scattering display element of Claim 43, the reflection means, which is part of the emission angle modification means, is a reflective film substrate; and

the scattering/transmission means is disposed between the reflective film substrate and an array substrate on which transparent pixel electrodes are formed and which is provided at a predetermined interval to the reflective film substrate.

According to Claim 60, in the scattering display element of Claim 59, a cross–section of the reflection means in vertical direction of the display screen is provided with a shape having sawtooth–shaped portions.

According to Claim 61, in the scattering display element of Claim 60, the inclination angle, with respect to a display surface, of an inclined surface in the cross–sectional shape having sawtooth–shaped portions is at least 5° and at most 30°.

According to Claim 62, in the scattering display element of Claim 59, a color filter is provided on either the reflective film substrate or the array substrate.

A scattering display element in accordance with Claim 63 comprises:

a scattering/transmission means for switching between a scattering state, in which incident light is scattered, and a transmitting state, in which incident light is transmitted;

a reflection means for reflecting light that is incident from a display side of the scattering/transmission means and scattered on a rear side, as

well as light that is transmitted by the scattering/transmission means; and

a means for confining within the scattering display element at least a portion of the light that is incident on the scattering display element when the scattering/transmission means is in the transmitting state.

Thus, by providing an emission angle modification means, such as a reflection means whose cross–sectional shape is that of half–convex lenses, a sawtooth shape with predetermined inclination angle, or a retroreflector shape, light that is incident on the scattering display element is emitted in a direction that is removed from the viewing range of the displayed image, so that the influence of reflected external light, such as luminance inversion or diminishing of contrast, can be eliminated easily. Furthermore, by setting the pitch of the sawtooth shape to random values, a deterioration of the image quality due to diffraction can be prevented, even when the pitch is small.

A scattering display element in accordance with Claim 64 comprises:

a scattering/transmission means for switching between a scattering state, in which incident light is scattered, and a transmitting state, in which incident light is transmitted;

a reflection means for reflecting light that is incident from a display side of the scattering/transmission means and scattered on a rear side, as well as light that is transmitted by the scattering/transmission means; and

an attenuation means for attenuating an amount of light reflected by

the reflection means.

According to Claim 65, in the scattering display element of Claim 64, the reflection means reflects and transmits light or reflects and absorbs light, and is part of the attenuation means.

According to Claim 66, in the scattering display element of Claim 65, the optical reflectivity of the reflection means is not higher than 90%.

According to Claim 67, in the scattering display element of Claim 65 the reflection means includes chromium.

According to Claim 68, in the scattering display element of Claim 64, the attenuation means includes a polarization means, which blocks light of a predetermined polarization.

According to Claim 69, in the scattering display element of Claim 68, the polarization means is arranged such that it blocks light that is polarized in a horizontal direction of the display screen.

According to Claim 70, in the scattering display element of Claim 68, the polarization means is disposed between the scattering/transmission means and the reflection means.

According to Claim 71, in the scattering display element of Claim 64, the attenuation means is a dispersive film of at least 70% and at most 95% transmissivity, disposed on a display surface side of the scattering/transmission means.

Thus, by providing an attenuation means for attenuating an amount of light reflected by the reflection means, the luminance of the reflected light

can be reduced, so that the influence of reflected external light, such as luminance inversion or diminishing of contrast, can be eliminated easily.

In accordance with Claim 72, in a method for manufacturing a display element comprising a reflection means for reflecting incident light, a step of forming said reflection means comprises the steps of:

forming a resin layer including micro-particles on a substrate; and

forming a reflective layer on the resin layer.

In accordance with Claim 73, in a method for manufacturing a display element comprising a reflection means for reflecting incident light, a step of forming said reflection means comprises the steps of:

forming a resin layer of a predetermined pattern on a substrate;

heating and softening the resin layer, such that its surface is provided with a predetermined curvature; and

forming a reflective layer on the resin layer.

In accordance with Claim 74, in a method for manufacturing a display element comprising a reflection means for reflecting incident light, a step of forming said reflection means comprises the steps of:

forming a resin layer on a substrate;

providing a surface of the resin layer with a predetermined shape by press-forming; and

forming a reflective layer on the resin layer.

In accordance with Claim 75, in a method for manufacturing a display element comprising a reflection means for reflecting incident light, a

step of forming said reflection means comprises the steps of:

forming a resin layer on a substrate;

forming a protective film of a predetermined pattern on the resin layer;

shaping the resin film by dry etching or sandblasting from a direction that is oblique with respect to the normal on the substrate;

forming a reflective layer on the resin layer after eliminating the protective film.

In accordance with Claim 76, in a method for manufacturing a display element comprising a reflection means for reflecting incident light, a step of forming said reflection means comprises the steps of:

forming a first resin layer on a portion of a substrate;

forming a second resin layer on a portion of a region including at least a portion of the first resin layer, so as to form a cross–section having a non–symmetric shape; and

forming a reflective layer on a region including the non–symmetric shape.

According to Claim 77, in the method for manufacturing a display element according to Claim 76, the second resin layer is formed after forming the first resin layer with a shape having oblique portions.

According to Claim 78, in the method for manufacturing a display element according to Claim 77, the second resin layer is formed with a shape having oblique portions.

According to Claim 79, in the method for manufacturing a display

element according to Claim 77, the first resin layer is provided with a shape having oblique portions by annealing.

According to Claim 80, in the method for manufacturing a display element according to Claim 78, the second resin layer is provided with a shape having oblique portions by annealing.

According to Claim 81, in the method for manufacturing a display element according to Claim 77, the non–symmetric shape includes at least a sawtooth–shaped portion.

According to Claim 82, in the method for manufacturing a display element according to Claim 78, the non–symmetric shape includes at least a sawtooth–shaped portion.

According to Claim 83, in the method for manufacturing a display element according to Claim 79, the non–symmetric shape includes at least a sawtooth–shaped portion.

According to Claim 84, in the method for manufacturing a display element according to Claim 80, the non–symmetric shape includes at least a sawtooth–shaped portion.

According to Claim 85, in the method for manufacturing a display element according to Claim 76,

the first resin layer and the second resin layer are made of photosensitive resin; and

the steps of forming the first resin layer and the second resin layer on a portion of the substrate include forming a resin layer on an entire substrate, followed by exposing the resin layer through a first light–blocking

mask and a second light–blocking mask having predetermined patterns, and developing, so as to form a shape with non–symmetric cross–section.

According to Claim 86, in the method for manufacturing a display element according to Claim 85, an exposure portion of the first light–blocking mask is shifted with respect to an exposure portion of the second light–blocking mask, so that said exposing forms a second resin layer on a portion of a region including at least a portion of the first resin layer.

According to Claim 87, in the method for manufacturing a display element according to Claim 85, the photosensitive resin is a positive photosensitive resin, and light–blocking portions of the second light–blocking mask are larger than light–blocking portions of the first light–blocking mask.

According to Claim 88, in the method for manufacturing a display element according to Claim 87, a width of light–blocking portions of the second light–blocking mask is larger than a width of the light–blocking portions of the first light–blocking mask.

According to Claim 89, in the method for manufacturing a display element according to Claim 85, the photosensitive resin is a negative photosensitive resin, and light–blocking portions of the second light–blocking mask are smaller than light–blocking portions of the first light–blocking mask.

According to Claim 90, in the method for manufacturing a display element according to Claim 89, a width of light–blocking portions of the second light–blocking mask is smaller than a width of the light–blocking

portions of the first light–blocking mask.

According to Claim 91, in the method for manufacturing a display element according to Claim 85, the exposure with the first light–blocking mask and the exposure with the second light–blocking mask is performed by irradiating light from a direction of a normal on the substrate.

According to Claim 92, in the method for manufacturing a display element according to Claim 85, at least one of the exposure with the first light–blocking mask and the exposure with the second light–blocking mask is performed by irradiating light from a direction of a normal on the substrate.

In accordance with Claim 93, in a method for manufacturing a display element comprising a reflection means for reflecting incident light, a step of forming said reflection means comprises the steps of:

forming said reflection means;

partially forming a first resin layer on a substrate;

forming a shape having a non–symmetric cross section by partially forming a second resin layer on a portion of a region including at least a portion of the first resin layer and then eliminating at least a portion of the first resin layer or the second resin layer; and

forming a reflective layer on a region including this non–symmetric shape.

According to Claim 94, in the method for manufacturing a display element according to Claim 93, the step of eliminating the resin layer is performed by dry etching with a mask of a predetermined pattern.

According to Claim 95, in the method for manufacturing a display element according to Claim 93, the non–symmetric shape includes at least a sawtooth–shaped portion.

According to Claim 96, in the method for manufacturing a display element according to Claim 72, the reflective layer is an electrode for driving the display element.

Thus, a reflection means that is scattering and modifies the emission angle can be manufactured easily, and the manufacturing costs can be reduced.

Furthermore, to attain the afore–mentioned objects, a scattering–mode liquid crystal display device in accordance with Claim 97, performing display by switching a liquid crystal layer between a scattering state and a transmitting state,

has luminance – voltage characteristics that exhibit a peak in the luminance level as the liquid crystal layer is changed from the scattering state to the transmitting state, when viewing from a predetermined viewing direction; and

a driving voltage range is set to a range between a voltage at the luminance peak in the luminance – voltage characteristics and a voltage at which the luminance level is substantially zero.

With this configuration, there is a peak luminance in the luminance –

voltage characteristics, so that a display with higher luminance and therefore larger brightness than in the conventional examples can be achieved by setting the driving voltage range to a range between the voltage at this peak luminance and a voltage at which the luminance level is substantially 0%. Furthermore, when setting the driving voltage range to this range, there is no peak luminance in the luminance – voltage characteristics, and it is possible to prevent the gray-scale inversion that is caused by the existence of a peak luminance in the luminance – voltage characteristics of the conventional examples.

In accordance with Claim 98, in a scattering–mode liquid crystal display device performing display by switching a liquid crystal layer between a scattering state and a transmitting state,

the scattering mode is a normally–white mode, in which the liquid crystal layer is in the scattering state when no voltage is applied, and the display is bright;

the liquid crystal display device has luminance – voltage characteristics in which, as the applied voltage is increased from 0V, the luminance level increases once from an initial level until it reaches a peak, and then decreases to substantially zero, when viewing from a predetermined viewing direction; and

a driving voltage range is set to a range between a voltage at which the luminance level in the luminance – voltage characteristics peaks and a voltage at which the luminance level is substantially zero.

With this configuration, a display that is brighter than in the conventional examples is possible, and a normally–white–mode liquid crystal display device can be realized, in which gray-scale inversion is prevented.

In accordance with Claim 99, in scattering–mode liquid crystal display device performing display by switching a liquid crystal layer between a scattering state and a transmitting state,

the scattering mode is a normally–black mode, in which the liquid crystal layer is in the transmitting state when no voltage is applied, and the display is dark;

the liquid crystal display device has luminance – voltage characteristics in which, as the applied voltage is increased from 0V until reaching a threshold voltage, the luminance level is substantially zero, and as the applied voltage increases beyond the threshold voltage, the luminance increases until it reaches a peak, and then decreases, when viewing from a predetermined viewing direction; and

a driving voltage range is set to a range between the threshold voltage at which the luminance level in the luminance – voltage characteristics starts to change and a voltage at which the luminance level peaks.

In accordance with Claim 100, there is a plurality of peaks of the luminance level in the luminance – voltage characteristics, and wherein the driving voltage range is set to a range between the highest voltage of the

voltages at those peaks and a voltage at which the luminance level is substantially zero.

In accordance with Claim 101, there is a plurality of peaks of the luminance level in the luminance – voltage characteristics, and wherein the driving voltage range is set to a range between the threshold voltage at which the luminance level starts to change from zero and the lowest voltage of the voltages at those peaks.

In accordance with Claim 102, the viewing direction is set to a direction that is different from an emission direction in which light is emitted frontward from the liquid crystal layer when the liquid crystal layer is in the transmitting state.

In accordance with Claim 103, the viewing direction is set to a direction that is different from an emission direction in which light is emitted frontward from the liquid crystal layer when the liquid crystal layer is in the transmitting state.

In accordance with Claim 104, the viewing direction is set to a direction that is different from an emission direction in which light is emitted frontward from the liquid crystal layer when the liquid crystal layer is in the transmitting state.

In accordance with Claim 105, the liquid crystal display device is driven by bias driving.

In accordance with Claim 106, the liquid crystal display device is driven by bias driving.

In accordance with Claim 107, the bias voltage for the bias driving

can be adjusted.

In accordance with Claim 108, the bias voltage for the bias driving can be adjusted.

In accordance with Claim 109, the liquid crystal display device further comprises a driving voltage adjustment means for adjusting the driving voltage in accordance with a change in the luminance – voltage characteristics such that the driving voltage is in said driving voltage range.

In accordance with Claim 110, the liquid crystal display device further comprises a driving voltage adjustment means for adjusting the driving voltage in accordance with a change in the luminance – voltage characteristics such that the driving voltage is in said driving voltage range.

In accordance with Claim 111, the liquid crystal display device further comprises a driving voltage adjustment means for adjusting the driving voltage in accordance with a change in the luminance – voltage characteristics such that the driving voltage is in said driving voltage range.

In accordance with Claim 112, the liquid crystal display device further comprises a detection means for detecting a voltage substantially corresponding to a peak value in the luminance level, and wherein the driving voltage adjustment means adjusts the driving voltage in accordance with a result of this detection.

In accordance with Claim 113, the liquid crystal display device further comprises a detection means for detecting a voltage substantially corresponding to a peak value in the luminance level, and wherein the driving voltage adjustment means adjusts the driving voltage in accordance

with a result of this detection.

In accordance with Claim 114, the liquid crystal display device further comprises a detection means for detecting a voltage substantially corresponding to a peak value in the luminance level, and wherein the driving voltage adjustment means adjusts the driving voltage in accordance with a result of this detection.

In accordance with Claim 115, the liquid crystal display device further comprises a detection means for detecting a temperature at which the liquid crystal display device is used, and wherein the driving voltage adjustment means adjusts the driving voltage in accordance with a result of this detection.

In accordance with Claim 116, the liquid crystal display device further comprises a detection means for detecting a temperature at which the liquid crystal display device is used, and wherein the driving voltage adjustment means adjusts the driving voltage in accordance with a result of this detection.

In accordance with Claim 117, the liquid crystal display device further comprises a detection means for detecting a temperature at which the liquid crystal display device is used, and wherein the driving voltage adjustment means adjusts the driving voltage in accordance with a result of this detection.

With this configuration, a display that is brighter than in the conventional examples is possible, and a normally–black–mode liquid crystal

display device can be realized, in which gray-scale inversion is prevented.

In accordance with Claim 118, a reflector for reflecting light that is incident from a front side of the liquid crystal layer and emitting it to the front side is provided on a rear side of the liquid crystal layer.

In accordance with Claim 119, a reflector for reflecting light that is incident from a front side of the liquid crystal layer and emitting it to the front side is provided on a rear side of the liquid crystal layer.

In accordance with Claim 120, a reflector for reflecting light that is incident from a front side of the liquid crystal layer and emitting it to the front side is provided on a rear side of the liquid crystal layer.

With this configuration, a display that is brighter than in the conventional examples is possible, and a reflective liquid crystal display device can be realized, in which gray-scale inversion is prevented.

In accordance with Claim 121, the liquid crystal display device further comprises a light source on a rear side of the liquid crystal layer, wherein oblique light from the light source is transmitted through the liquid crystal layer and emitted to a front side.

In accordance with Claim 122, the liquid crystal display device further comprises a light source on a rear side of the liquid crystal layer, wherein oblique light from the light source is transmitted through the liquid crystal layer and emitted to a front side.

In accordance with Claim 123, the liquid crystal display device further comprises a light source on a rear side of the liquid crystal layer, wherein oblique light from the light source is transmitted through the liquid crystal layer and emitted to a front side.

With this configuration, a display that is brighter than in the conventional examples is possible, and a transmissive liquid crystal display device can be realized, in which gray-scale inversion is prevented.

In accordance with Claim 124, display is performed by active matrix driving.

In accordance with Claim 125, display is performed by active matrix driving.

In accordance with Claim 126, display is performed by active matrix driving.

With this configuration, a display that is brighter than in the conventional examples is possible, and an active matrix liquid crystal display device can be realized, in which gray-scale inversion is prevented.

In accordance with Claim 127, display is performed by simple matrix driving.

In accordance with Claim 128, display is performed by simple matrix driving.

In accordance with Claim 129, display is performed by simple matrix driving.

With this configuration, a display that is brighter than in the conventional examples is possible, and simple matrix liquid crystal display device can be realized, in which gray-scale inversion is prevented.

In accordance with Claim 130, in a method for driving a scattering–mode liquid crystal display device, display is performed by switching a liquid crystal layer between a scattering state and a transmitting state, and

the display device is driven by bias driving.

In accordance with Claim 131, the display device is driven by active driving with an active element array.

In accordance with Claim 132, the bias driving is inversion driving.

In accordance with Claim 133, the bias driving is floating gate driving.

In accordance with Claim 134, the bias driving is capacitive coupling driving.

In accordance with Claim 135, said predetermined voltage generated by said bias driving means is variable.

In accordance with Claim 136, a scattering–mode liquid crystal display device performing display by switching a liquid crystal layer between a scattering state and a transmitting state,

has luminance – voltage characteristics in which, as the liquid crystal layer changes from the scattering state to the transmitting state, there is a luminance level that is higher than the luminance level when the applied voltage is 0V, when viewing from a predetermined viewing direction.

In accordance with Claim 137, the driving voltage range is set to a range between a voltage at which a luminance level in the luminance – voltage characteristics is higher than the luminance at an applied voltage of 0V and a voltage at which the luminance level has monotonously decreased from said higher luminance level to about zero.

In accordance with Claim 138, a luminance level that is higher than the luminance level at an applied voltage of 0V, which changes depending on the usage temperature of the liquid crystal display device, is configured to be highest within a usage temperature range.

In accordance with Claim 139, a luminance level that is higher than the luminance level at an applied voltage of 0V, which changes depending on the usage temperature of the liquid crystal display device, is configured to be highest approximately at room temperature.

In accordance with Claim 140, a liquid phase – isotropic phase phase shift temperature in a liquid crystal material of the liquid crystal layer is at least 20°C higher than an upper limit of the usage temperature range of the liquid crystal device.

In accordance with Claim 141, a liquid phase – isotropic phase phase shift temperature in a liquid crystal material of the liquid crystal layer is at least 80°C.

In accordance with Claim 142, a luminance level peak, which changes depending on the usage temperature of the liquid crystal display device, is configured to be highest within a usage temperature range.

In accordance with Claim 143, a luminance level peak, which changes depending on the usage temperature of the liquid crystal display device, is configured to be highest approximately at room temperature.

In accordance with Claim 144, a liquid phase – isotropic phase phase shift temperature in a liquid crystal material of the liquid crystal layer is at least 20°C higher than an upper limit of the usage temperature range of the liquid crystal device.

In accordance with Claim 145, a liquid phase – isotropic phase phase shift temperature in a liquid crystal material of the liquid crystal layer is at least 80°C.

In accordance with Claim 146,

$50\exp(-0.4d) < SG < 360\exp(-0.47d)$ is satisfied,

wherein d(μm) is the thickness of the liquid crystal layer and SG is the scattering gain of the liquid crystal layer.

In accordance with Claim 147, satisfying

$50\exp(-1.6\Delta n \cdot d) < SG < 360\exp(-1.88\Delta n \cdot d)$,

wherein d(μm) is the thickness of the liquid crystal layer, SG is the scattering gain of the liquid crystal layer, and Δn is the birefringence anisotropy of the liquid crystal material

In accordance with Claim 148, the scattering gain of the liquid crystal layer is at least 10 and at most 200.

In accordance with Claim 149, the scattering gain of the liquid crystal layer in a usage temperature range of the liquid crystal display device is at least 10 and at most 200.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a simplified cross-sectional view of a liquid crystal display element 101A in accordance with Embodiment A1 of the present invention.

Fig. 2 is a diagram illustrating the display principle of the liquid crystal display element 101A.

Fig. 3 shows the voltage – reflectivity characteristics of the liquid crystal display element 101A.

Fig. 4 illustrates the scattering properties of the liquid crystal display element 101A.

Fig. 5 is a graph showing the relation between scattering gain and contrast.

Fig. 6 is a graph illustrating how the scattering gain that is necessary for attaining a tolerable contrast depends on the panel gap.

Fig. 7 is a graph showing the relation between scattering gain and the maximum contrast.

Fig. 8 is a graph showing the relation between the panel contrast and the product Δnd.

Fig. 9 is a simplified cross-sectional view of a liquid crystal display element 101B in accordance with Embodiment A3 of the present invention.

Fig. 10 is a simplified cross-sectional view of a liquid crystal display

element 101C in accordance with Embodiment A4 of the present invention.

Fig. 11 is a graph illustrating how the scattering gain that is necessary for attaining a tolerable contrast for red depends on the panel gap.

Fig. 12 illustrates the relation between the scattering gains for R, G, and B and the particle diameter.

Fig. 13 is a simplified cross-sectional view of a liquid crystal display element 101D in accordance with Embodiment A5 of the present invention.

Fig. 14 schematically illustrates the relation between the R, G and B layer thicknesses necessary for attaining suitable scattering gains.

Fig. 15 is a cross-sectional view of the configuration of the display element in Embodiment B1.

Fig. 16 illustrates the refractive index of the liquid crystal molecules.

Fig. 17 illustrates the configuration of the reflector of the display element in Embodiment B1.

Fig. 18 illustrates the light path of reflected light in the display element in Embodiment B1.

Fig. 19 illustrates the directions of reflected light in the display element in Embodiment B1.

Fig. 20 is a cross-sectional view showing the configuration of the display element in Embodiment B2.

Fig. 21 is a perspective view showing the configuration of the lens sheet film of the display element in Embodiment B2.

Fig. 22 shows the configuration of the reflector of the display element in Embodiment B3.

Fig. 23 illustrates the light path of reflected light in the display element in Embodiment B3.

Fig. 24 illustrates the directions of reflected light in the display element in Embodiment B3.

Fig. 25 is a cross–sectional view of the configuration of the display element in Embodiment B4.

Fig. 26 illustrates the light path of reflected light in the display element in Embodiment B4.

Fig. 27 illustrates the light path of reflected light in the display element in Embodiment B4.

Fig. 28 is a graph showing the relation between incidence angle and emission angle in the display element in Embodiment B4.

Fig. 29 is a graph showing the relation between inclination angle and emission angle in the display element in Embodiment B4.

Fig. 30 is a cross–sectional view of the configuration of the display element in Embodiment B5.

Fig. 31 is a cross–sectional view of the configuration of the display element in Embodiment B6.

Fig. 32 is a planar view of the configuration of the reflector of the display element in Embodiment B7.

Fig. 33 is a cross–sectional view of the configuration of the display element in Embodiment B7.

Fig. 34 is a planar view of the configuration of the reflector of a display element in another example of Embodiment B7.

Fig. 35 shows the configuration of the lens sheet film in the display element in Embodiment B8.

Fig. 36 illustrates the light path of reflected light in the display element in Embodiment B8.

Fig. 37 shows the configuration of the reflector of the display element in Embodiment B9.

Fig. 38 illustrates the directions of reflected light in the display element in Embodiment B9.

Fig. 39 shows the configuration of the reflector of the display element in Embodiment B11.

Fig. 40 is a cross-sectional view of the configuration of the display element in Embodiment B13.

Fig. 41 is a cross-sectional view of the configuration of the display element in Embodiment B14.

Fig. 42 is a planar view of the configuration of reflector of the display element in Embodiment B14.

Fig. 43 is a cross-sectional view of the configuration of the display element in Embodiment B15.

Fig. 44 illustrates the steps for manufacturing the reflector of the display element in Embodiment B16.

Fig. 45 illustrates the steps for manufacturing the reflector of the display element in Embodiment B17.

Fig. 46 illustrates the steps for manufacturing the reflector of the display element in Embodiment B18.

Fig. 47 illustrates another example of the steps for manufacturing the reflector of the display element in Embodiment B18.

Fig. 48 illustrates the steps for manufacturing the reflector of the display element in Embodiment B19.

Fig. 49 is a simplified cross–sectional view of a liquid crystal display device 301 in accordance with the outline of Embodiment C.

Fig. 50 illustrates the operation of the liquid crystal display device 301 in accordance with the outline of Embodiment C.

Fig. 51 is a graph showing the luminance – voltage characteristics of the liquid crystal display device 301 in accordance with the outline of Embodiment C.

Fig. 52 is a simplified cross–sectional view of a liquid crystal display device 301A in accordance with Embodiment C1.

Fig. 53 is a simplified cross–sectional view of a liquid crystal display device 301B in accordance with Embodiment C2.

Fig. 54 is a graph showing the luminance – voltage characteristics of the in Embodiment C4.

Fig. 55 is a perspective view of the reflector used in the reflective liquid crystal display device in Embodiment C6.

Fig. 56 is cross–sectional view of Figs. 7 and 8.

Fig. 57 is a graph showing how the luminance – voltage characteristics of the liquid crystal display device in Embodiment C7 change with temperature.

Fig. 58 is a graph showing the voltage where the luminance peaks in

the liquid crystal display device in Embodiment C7 changes with temperature.

Fig. 59 is a block diagram showing the configuration of a liquid crystal display device in Embodiment C7, that is provided with a temperature sensor.

Fig. 60 is a block diagram showing the configuration of a liquid crystal display device in Embodiment C7, that is provided with a photo–sensor.

Fig. 61 is a graph showing the voltage where the luminance peaks in the liquid crystal display device in Embodiment C8 changes with temperature.

Fig. 62 is a graph showing the voltage where the luminance peaks in the liquid crystal display device in Embodiment C8 changes with temperature.

Fig. 63 is a graph showing the luminance – voltage characteristics of the liquid crystal display device in Embodiment C9.

Fig. 64 shows a configuration of the reflector of a conventional scattering display device.

Fig. 65 shows another configuration of the reflector of a conventional scattering display device.

Fig. 66 illustrates the display operation of a scattering display element.

Fig. 67 illustrates how the scattering display element is used.

Fig. 68 illustrates the directions of reflected light in a conventional

scattering display element.

Fig. 69 is a graph showing the luminance – voltage characteristics of a conventional liquid crystal display device.

BEST MODE FOR CARRYING OUT THE INVENTION

The following is a more specific description of the present invention, with reference to the preferred embodiments.

First of all, an Embodiment A of the present invention is explained, with reference to the accompanying drawings. In this Embodiment A, a higher luminance and a higher contrast can be attained by setting the scattering gain and the product of the level of anisotropy of the liquid crystal's refractive index and the thickness of the liquid crystal layer to suitable values.

Embodiment A1

Fig. 1 is a simplified cross–sectional view of a liquid crystal display element 101 in accordance with Embodiment A1 of the present invention. The liquid crystal display element 101 is a reflective liquid crystal display element, and is a normally–white–mode liquid crystal display element. The liquid crystal display element 101 includes an array substrate 102, an opposing substrate 103 arranged in opposition to the array substrate 102, and a polymer–dispersed liquid crystal layer 104 disposed between the array substrate 102 and the opposing substrate 103. The array substrate 102 and the opposing substrate 103 are transparent substrates made, for example, of

glass. A source line 106, a reflective pixel electrode 105 made of a reflective metal, and a thin film transistor (TFT) serving as a pixel switching element are formed on the array substrate 102. The reflective pixel electrode 105 is made, for example, of aluminum (Al) or chromium (Cr). The source line 106, the reflective pixel electrode 105, and the TFT are covered by an insulating film 107. A transparent opposing electrode 109 and an insulating film 110 are layered in that order on the inner side of the opposing substrate 103.

The polymer–dispersed liquid crystal layer 104 is made of a polymer 111 into which drops 112 of a liquid crystal are dispersed, wherein the liquid crystal used for these liquid crystal drops 112 has positive dielectric anisotropy.

The scattering gain SG of the polymer–dispersed liquid crystal layer 104 satisfies the relation set forth in Equation 1 below. Here, "scattering gain SG" is defined as SG = (panel luminance / panel illumination) × π, so that when the scattering gain is large, then the scattering effect is small, and when the scattering gain is small, then the scattering effect is large. For the scattering gain, the scattering gain with respect to green light was used.

(Equation 1) $50\exp(-0.4d) < SG < 360\exp(-0.47d)$

Here, d is the layer thickness of the polymer–dispersed liquid crystal layer 104 (referred to as "panel gap" in the following).

Setting the scattering gain of the polymer–dispersed liquid crystal layer 104 as specified by Equation 1, makes it possible to attain a reflective

liquid crystal display element with much higher luminance and contrast than in the conventional examples. The scattering gain can also be set by the product Δnd of the level of the refractive index anisotropy Δn and the panel gap d, or the size of the liquid crystal drops, as will be explained below.

Moreover, higher luminance and higher contrast are attained by satisfying Equation 1 when the level of the refractive index anisotropy Δn of the liquid crystal in the liquid crystal drops 112 at room temperature was roughly 0.25, but higher luminance and higher contrast are also attained by satisfying the following Equation 1' when the value of Δn is significantly different, for example when Δn is that of often used liquid crystal materials (for example, at least about 0.15 and at most 0.27).

(Equation 1') $50\exp(-1.6\Delta nd) < SG < 360\exp(-1.88\Delta nd)$

For regular panel parameters, such as liquid crystal material and panel gap, the values of the scattering gain SG that satisfy these Equations 1 and 1' are roughly between about 10 and 200 in a usage temperature range of 10°C to 60°C, for example.

Describing the operation of a liquid crystal display element in accordance with the present invention, the following is a discussion of the reasons behind this.

Fig. 2 is a diagram illustrating the display operation of the reflective liquid crystal display element. Explaining the display operation with reference to Fig. 2, when the voltage is OFF, the directors of the liquid crystal

in the liquid crystal drops 112 point into random orientations in 3D space as shown in Fig. 2(a), and therefore the panel is in the scattering state, due to the difference in the refractive indices of the liquid crystal and the polymer 113. In this situation, light 120 that is incident on the panel turns into scattered light 121, so that the display appears white. On the other hand, when the voltage is ON, the liquid crystal in the liquid crystal drops 112 is oriented substantially in the direction of the panel gap, as shown in Fig. 2(b). Therefore, the panel is in the transparent state, due to the matching refractive indices of the liquid crystal and the surrounding polymer 113. Consequently, the incident light 120 is not scattered, but reflected at the reflective pixel electrode, and emitted from the panel as specularly reflected light 122. In this situation, no light is emitted in the direction of the observer 125, so that the panel appears black.

Fig. 3 shows the voltage – reflectivity characteristics of a polymer–dispersed liquid crystal display element with this display operation. The graphs in Fig. 3 have been obtained experimentally by the inventors. The measurement parameters were the incidence angle of incident light $\theta 1 = 30°$ and the measurement angle $\theta 2 = 15°$ (see Fig. 2(b)). These parameters correspond to standard viewing conditions for reflective liquid crystal display elements.

As becomes clear from Fig. 3, as the applied voltage rises, the reflectivity increases at first, and then drops after reaching a peak value. This means that there is a peak reflectivity in the voltage – reflectivity characteristics of reflective polymer–dispersed liquid crystal display

elements. The existence of this peak reflectivity was first ascertained in the experimental results by the inventors of the present invention.

It seems that the existence of this peak reflectivity is due to the following principle, which is explained with reference to Fig. 4. In Fig. 4, the scattering orientation distribution 130 illustrates the scattering state of the panel when no voltage is applied (this corresponds to point A in Fig. 3), the scattering orientation distribution 131 illustrates the scattering state when the reflectivity is largest (this corresponds to point B in Fig. 3), and the scattering orientation distribution 132 illustrates the scattering state when an even higher voltage is applied (this corresponds to point C in Fig. 3). In case of a polymer–dispersed panel of normally–white mode, as the applied voltage increases, the scattering grows weaker, and the scattering orientation distribution is drawn out in the direction of specular reflection of the incident light. In this situation, from the position of the observer 125 in Fig. 4, the reflectivity of the scattering orientation distribution 131 is higher than the reflectivity of the scattering orientation distribution 130. And when the voltage is increased even further, the scattering orientation distribution 132 settles substantially in the direction of specular reflection, and the reflectivity in the direction of the observer 25 diminishes. For this reason, a peak appears in the reflectivity of the voltage – reflectivity characteristics. Directing their attention to these voltage – reflectivity characteristics, the inventors found that a higher luminance and a higher contrast can be attained by setting the luminance level at the peak reflectivity as white luminance, that is, by setting the range of the driving

voltage to the range between the voltage at which the luminance level peaks and a voltage at which the luminance level becomes substantially zero, or to a voltage range in which the luminance decreases monotonously from the peak value.

Conventionally, no mode was known, in which there is a peak reflectivity in the voltage – reflectivity characteristics. It seems that as the voltage – reflectivity characteristics were obtained by measuring the light reflecting at the panel front for obliquely incident light and the scattering gain SG for the transmission case was set to about 1 to 2, a similar scattering gain was used for the reflecting case as well, so that the peak reflectivity was small, and it was not possible to recognize the existence of the peak reflectivity.

Referring to Fig. 3, the following is an explanation of the relation between the scattering gain and the voltage – reflectivity characteristics. In conventional reflective liquid crystal display elements using a black absorber, the scattering gain SG is about 1 to 2. This is because usually, the scattering gain is set to about SG = 1 to obtain complete scattering in the scattering state (initial state) of transmissive liquid crystal display elements, and trusting that in reflective liquid crystal display elements, too, high luminance and high contrast can also be realized by achieving complete scattering, the scattering gain is set to about SG = 1. However, the inventors have confirmed experimentally that there is a peak reflectivity (corresponding to a peak luminance) in the voltage – reflectivity characteristics as explained above, and the voltage – reflectivity

characteristics for SG = 1 are illustrated by the curve M1 in Fig. 3. Consequently, in conventional examples, in which the scattering gain is set to SG = 1, there is a situation where the luminance level is actually larger than in the state in which no voltage is applied (that is, when the applied voltage is 0V). And when SG = 1, then the reflectivity for oblique light settles at a value that is significantly different from 0%, since the corresponding refractive indices of the polymer and the liquid crystal are different, even though the liquid crystal molecules are arranged perpendicularly with respect to the substrate. In this situation, since a black absorber is used, the black of the black absorber is projected as the black level, so that a sufficient black level can be attained even though the reflectivity is not 0%. However, the contrast is not high.

On the other hand, the voltage – reflectivity characteristics for SG = 100 for example when the panel gap is relatively large are illustrated by the line M2 in Fig. 3, although they will also depend on other conditions. It can be seen that, as the voltage is increased, the reflectivity rises somewhat from the initial state, and then diminishes and settles at approximately 0%. It seems that when the scattering gain is large (that is, when there is little scattering effect), there is little change in the scattering of obliquely incident light. And it seems that as a consequence, the peak reflectivity is also small. On the other hand, when increasing the voltage, the reflectivity settles at approximately 0%, because the scattering effect is small to begin with. Thus, regardless if the scattering gain is small or too large, it is not possible to attain high luminance and high contrast. The existence of an optimum

scattering gain for increasing luminance and contrast thus can be acknowledged. According to the results of the experiments carried out by the inventors, the optimum scattering gain is at about 10 to 20. Thus, setting the scattering gain to the optimum value, the line M3 in Fig. 3 can be attained, and higher luminance and higher contrast can be achieved.

On the other hand, the scattering gain at which a predetermined contrast is attained is interrelated with the panel gap, and to attain an optimum scattering gain, the size of the panel gap has to be considered. To specifically determine the optimum scattering gain, several polymer–dispersed liquid crystal panels with various scattering properties were evaluated, and as a result, the relation of scattering gain and contrast shown in Fig. 5 was obtained. For the scattering gain, the scattering gain measured on a transmissive panel was used. For the contrast, the results measured under the same measuring parameters (that is, angle of incident light $\theta 1 = 30°$ and measurement angle $\theta 2 = 15°$) as for the above–mentioned voltage – reflectivity characteristics were used. As becomes clear from Fig. 5, it can be ascertained that there are scattering gains, at which the contrast becomes largest, and that these scattering gains differ depending on the panel gap. This means that if the panel gap is set to a certain value, then this decides the scattering gain for attaining the maximum contrast. Here, for the liquid crystal display element according to the present invention, it is desirable to attain a contrast of at least 70% of the maximum contrast, and the range of scattering gains in which a contrast of at least 70% of the maximum contrast is attained was determined. It should be noted that the

contrast of conventional reflective panels is usually about 10, and in large cases about 15. Consequently, if the contrast is at least 70% of the maximum contrast, a significantly higher contrast than in conventional panels can be achieved.

The range of the scattering gains in which a contrast of at least 70% of the maximum contrast is attained was determined specifically by the following procedure: In the scattering gain – contrast graphs for the various panel gaps d (in Fig. 5, the graph for d = 4.5μm is indicated by reference marker L1, the graph for d = 7μm is indicated by reference marker L2, and the graph for d = 10μm is indicated by reference marker L3), the scattering gains attaining at least 70% of the maximum contrast (in Fig. 5, the lines m1, m2, and m3 mark lines corresponding to 70% of the maximum contrast for d = 4.5μm, 7μm, and 10μm) were determined, and successively plotting these values, the relation between the panel gap and the scattering gain as shown in Fig. 6 was obtained. More specifically, the points A1, A2, A3; B1, B2, B3; C1, C2, C3 in Fig. 5 were plotted in Fig. 6. Then, the range of suitable scattering gains was calculated from the relation between panel gaps and scattering gains in Fig. 6.

Here, line P1 in Fig 6 marks the upper limit of the tolerance range, line P2 in Fig 6 marks a range of optimum contrast, and line P3 in Fig 6 marks the lower limit of the tolerance range. Consequently, it can be ascertained that the range where the scattering gain is suitable, is the range defined by the lines P1 and P3. Expressing line P1 as a function gives SG = 360exp(–0.47d), and expressing line P3 as a function gives SG = 50exp(–0.4d).

Consequently, it will be appreciated that the range where the scattering gain SG is suitable is given by $50\exp(-0.4d) < SG < 360\exp(-0.47d)$.

Expressing line P2 as a function gives $SG = 265\exp(-0.5d)$. Consequently, setting the scattering gain SG to $265\exp(-0.5d)$ achieves the maximum contrast at that panel gap.

Furthermore, it was ascertained in experiments carried out by the inventors that the relation between the maximum contrast and the panel gap is as shown in Fig. 7. Fig. 7 suggests that the maximum contrast is larger the smaller the panel gap is. However, when the panel gap is less than 3μm, it is difficult to actually make it uniform. On the other hand, when the panel gap is larger than 8μm, then the driving voltage increases, which is not suitable for reflective panels. It is therefore preferable that the panel gap d is set to at least 3μm and at most 8μm.

<u>More Specific Example of Embodiment A1</u>

The following is an explanation of a more specific example of Embodiment A1.

The liquid crystal display element 101 shown in Fig. 1 was manufactured by the following method. A TFT element, a source line 106, and a reflective pixel electrode 105 made of aluminum were formed on a transparent substrate made of glass, forming an array substrate 102. The reflective pixel electrode 105 serves as a flat mirror finished reflector. Moreover, a transparent opposing electrode 109, for example, was formed on the opposing substrate 103. Then, the upper and lower substrates 102 and

103 were laminated on one another with a panel gap of 5μm. Next, a polymer–dispersed liquid crystal material (trade name: PNM201 by Dainippon Ink and Chemicals, Inc.) was introduced by vacuum injection between the substrates 102 and 103. Then, UV light was irradiated on the panel, and the polymer–dispersed liquid crystal material, which has been introduced by vacuum injection, was polymerized, thereby producing a polymer–dispersed liquid crystal panel.

The resulting panel was evaluated by measuring its voltage – reflectivity characteristics. Thus, the characteristics in Fig. 3 were obtained. Then, a large number of panels with differing liquid crystal particle diameters and panel gaps were produced, and the relation between scattering gain and contrast was evaluated. Thus, the characteristics in Fig. 5 were obtained. Using the same material as in the case of reflective panels, polymer–dispersed liquid crystal layers with the same particle diameter and the same panel gaps were produced separately in transmissive panels, and the scattering gain was evaluated from the transmission light of the panel. The contrast was then determined from the value of the peak reflectivity at a polar angle of 15° when light is incident at a polar angle of 30° and from the luminance at the time the largest voltage is applied.

Moreover, the relation between the range of suitable scattering gains and the panel gap shown in Fig. 6 was obtained from Fig. 5. Here, the suitable range is the range at which a contrast of at least 70% of the maximum contrast can be achieved. From Fig. 5, it will be appreciated that a high contrast is obtained when the scattering gain SG is given by

$$50\exp(-0.4d) < SG < 360\exp(-0.47d).$$

Here, d(μm) is the panel gap. Moreover, the contrast is maximized when SG $= 265\exp(-0.5d)$. More specifically, when the panel gap is 4.5μm, suitable scattering gains are in the range of approximately 10 to 40. And when the gain is 25, a maximum contrast of about 55 can be attained. As shown in Fig. 7, the maximum value of the contrast depends on the panel gap, and an extremely superior display with a contrast of more than 30 can be attained when the panel gap is at least 3μm and at most 8μm.

In this example, the contrast for determining the range of suitable scattering gains is set to at least 70% of the maximum contrast, but, depending on necessity, it is also possible to use a predetermined contrast of at least 50% of the maximum contrast, for example. For at least 50% of the maximum contrast, the range of suitable scattering gains can be determined from Fig. 5 in the same manner as for at least 70% of the maximum contrast to be given as

$$37\exp(-0.37d) < SG < 275\exp(-0.31d) \text{ or}$$

$$37\exp(-1.48\Delta n \cdot d) < SG < 275\exp(-1.24\Delta n \cdot d).$$

For at least 90% of the maximum contrast, the range of suitable scattering gains is given as

$$177\exp(-0.52d) < SG < 229\exp(-0.41d) \text{ or}$$

$$177\exp(-2.08\Delta n \cdot d) < SG < 229\exp(-1.64\Delta n \cdot d).$$

More specifically, for at least 70% of the maximum contrast with a panel gap of 3μm, for example, the range of suitable scattering gains is from 15 to 108, and the optimum scattering gain is 80.

Embodiment A2

A liquid crystal display element in accordance with Embodiment A2 has basically the same structure as Embodiment 1. However, it is characterized in that the product Δnd of the level of the refractive index anisotropy Δn of the liquid crystal in the liquid crystal drops and the panel gap d is at least 0.6μm and at most 2.2μm. With this configuration, too, it is possible to achieve a reflective polymer–dispersed liquid crystal display element with high luminance and high contrast.

The reasons for this are explained in the following. The scattering gain depends on the level of the refractive index anisotropy of the liquid crystal, the panel gap, and the particle diameter of the liquid crystal drops, among others. (Because these parameters can be changed independently from one another, there is a large number of parameter combinations for the same scattering gain.) Consequently, the scattering gain can be regulated with the product Δnd of the level of the refractive index anisotropy Δn of the liquid crystal in the liquid crystal drops and the panel gap d. Based on this reasoning, the inventors experimentally obtained the relation between Δnd and the contrast, as shown in Fig. 8. Here, in Embodiment A2, the contrast was set to at least 30. In Fig. 8, it can be ascertained that the product Δnd corresponding to a contrast of at least 30 is at least 0.6μm and at most 2.2μm. Consequently, a reflective polymer–dispersed liquid crystal display element with high luminance and high contrast can be achieved by selecting the liquid crystal material and setting the panel gap such that Δnd becomes at

least 0.6μm and at most 2.2μm.

For the same reasons as explained in Embodiment A1, it is preferable that the panel gap d is at least 3μm and at most 8μm. Moreover, it is preferable that the refractive index anisotropy Δn of the liquid crystal is at least 0.15 and at most 0.27, and that the particle diameter of the liquid crystal drops is at least 0.7μm and at most 2μm. The panel gap d, the refractive index anisotropy Δn of the liquid crystal, and the particle diameter of the liquid crystal drops can be selected and combined as suitable within these ranges, so as to set Δnd to a range of at least 0.6μm and at most 2.2μm. As long as the scattering gain is within a suitable range, any combination of particle diameter, Δn, and panel gap within this range is possible.

More Specific Example of Embodiment A2

The following is an explanation of a more specific example of Embodiment A2.

A large number of panels with differing refractive index anisotropy Δn of the liquid crystal, panel gaps d and particle diameter R of the liquid crystal drops, having substantially the same configuration as Embodiment A1 were produced, and the voltage – reflectivity characteristics were measured. The characteristics were measured with light that is incident at a polar angle of 30° and reflected at a polar angle of 15°. From these measurement results, the relation between the panel contrast and the product Δnd as shown in Fig. 8 was obtained. As becomes clear from Fig. 8, the contrast has a peak with respect to Δnd. Moreover, a superior display

with a contrast of at least 30 is obtained when Δnd is at least 0.6μm and at most 2.2μm. In this situation, the birefringence of the liquid crystal is at least 0.15 and at most 0.27. Moreover, since the panel gap is set to at least 3μm and at most 8μm, the particle diameter of the liquid crystal drops should be at least 0.7μm and at most 2μm, considering the scattering effect. The refractive index anisotropy of the liquid crystal, the panel gap and the particle diameter are combined as suitable within the above–mentioned ranges. In particular when the panel gap is set to not more than 8μm with regard to a reduction of the driving voltage, the particle diameter of the liquid crystal drops should be set to at least 0.5μm and at most 2μm.

Embodiment A3

Fig. 9 is a simplified cross–sectional view of a liquid crystal display element 101B in accordance with Embodiment A3 of the present invention. In this embodiment, elements corresponding to Embodiment A1 are marked with the same reference symbols, and their further explanation has been omitted. The polymer–dispersed liquid crystal layer 104A in this embodiment includes a polymer 111, and two types of liquid crystal drops 112A and 112B. The liquid crystal drops 112A are disposed within the polymer–dispersed liquid crystal layer 104A, and have the same shape as the liquid crystal drops 112 inside the polymer–dispersed liquid crystal layer in Embodiment A1. On the other hand, the liquid crystal drops 112B are arranged as semi–spheres at the border of the substrates 102 and 103. The directors of the liquid crystals inside the liquid crystal drops 112B are

arranged substantially uniformly in parallel to the substrate 102 and 103, whereas the directors of the liquid crystals inside the liquid crystal drops 112A point into random directions in 3D space.

Orientation films 140 and 141 are formed on the substrates 102 and 103, on which the liquid crystal drops 112B are to be formed, and the materials are selected such that the wettability of the liquid crystal material with respect to these orientation films 140 and 141 is higher than that of the polymer material. Furthermore, the orientation films 140 and 141 are subjected to a horizontal orientation process by rubbing.

The effect attained by forming the liquid crystal drops 112B with this configuration is that the scattering at the substrate borders is reduced, and the scattering gain is increased. Consequently, the scattering gain of the panel can be adjusted to a suitable range, and a higher luminance and higher contrast can be attained by adjusting the size of the liquid crystal drops 112B, without changing the liquid crystal composition or the particle diameter of the liquid crystal drops, and without increasing the liquid crystal fraction.

The orientation film 140 and the orientation film 141 can be rubbed in the same direction, or in different directions. However, when they are rubbed in the same direction, there is the effect that the scattering at the borders between the substrates 102 and 103 is reduced even further. Moreover, the panel gap d is set to at least 3μm and at most 8μm. This is for the same reasons as the restrictions of the panel gap d in Embodiment A1.

<u>More Specific Example of Embodiment A3</u>

The following is an explanation of a more specific example of Embodiment A3.

The liquid crystal display element 101B according to Embodiment A3 was manufactured by the following method. First, a TFT element, a source line 106, and a reflective pixel electrode 105 made of aluminum were formed on a transparent substrate made of glass, forming an array substrate 102. The reflective pixel electrode 105 was as a flat mirror finished reflector. Moreover, a transparent opposing electrode 109, for example, was formed on the opposing substrate 103. After the orientation films 140 and 141 (trade name: AL5417 by Japan Synthetic Rubber Corp., Ltd.) were formed on the upper and lower substrates 102 and 103, the orientation films 140 and 141 were subjected to a rubbing process. The rubbing process was carried out such that the rubbing directions were parallel after laminating the upper and lower substrates 102 and 103. Then, the upper and lower substrates 102 and 103 were laminated at a panel gap of 5μm. Next, a polymer–dispersed liquid crystal material (trade name: PNM201 by Dainippon Ink and Chemicals, Inc.) was introduced by vacuum injection between the substrates 102 and 103. Then, UV light was irradiated on the panel, and the polymer–dispersed liquid crystal material was polymerized, thereby producing a polymer–dispersed liquid crystal panel in accordance with Embodiment A3. Furthermore, separately from the polymer–dispersed panel in accordance with Embodiment A3, another polymer–dispersed panel for evaluation was prepared in the same manner as

described above, except that it the orientation films 140 and 141 were not formed. The scattering gain of this evaluation panel was 30, and therefore larger than the 15 when no rubbing process is performed. Moreover, when the substrates of the evaluation panel were peeled apart, and the borders were examined with an image forming device, semi–spherical liquid crystal drops were formed at the borders. By preparing a panel using a substrate that has been subjected to a rubbing process in this manner, the liquid crystal at the borders can be oriented substantially uniformly in parallel to the rubbing direction, and the scattering at the borders can be reduced. Thus, it is possible to adjust the scattering gain as desired, and the scattering gain can be set, for example, to 25, at which a high contrast can be achieved.

The orientation films formed on the substrates can also be different from the ones described above, as long as the liquid crystal drops deposit in semi–spheres on the substrates during the polymer / liquid crystal phase separation. In this situation, the wettability of the liquid crystal material with respect to the orientation films should be higher than that of the polymer material. Moreover, the rubbing directions can be any direction, but the scattering decreases when the rubbing directions of the upper and lower substrates match. Thus, the directions for the upper and lower substrates can be changed in accordance with the scattering degree.

Embodiment A4

Fig. 10 is a simplified cross–sectional view of a liquid crystal display

element 101C in accordance with Embodiment A4 of the present invention. In this embodiment, elements corresponding to Embodiment A1 are marked with the same reference symbols, and their further explanation has been omitted. The liquid crystal display element 101C in accordance with this embodiment is a reflective liquid crystal display element provided with a color filter 160 including a red (R) color filter portion 161, a green (G) color filter portion 162, and a blue (B) color filter portion 163. In the drawing, numeral 165 denotes a TFT element connected to an R reflection pixel electrode 105a, numeral 166 denotes a TFT element connected to a G reflection pixel electrode 105b, and numeral 167 denotes a TFT element connected to a B reflection pixel electrode 105c. Moreover, numeral 164 denotes an insulating layer, and numeral 168 denotes a black matrix. Numeral 104G denotes a G pixel region in the polymer-dispersed liquid crystal layer 104, numeral 104B denotes a B pixel region in the polymer-dispersed liquid crystal layer 104, and numeral 104R denotes an R pixel region in the polymer-dispersed liquid crystal layer 104.

Whereas the previously described Embodiments A1 to A3 are liquid crystal display elements without color filters, the liquid crystal display element in the present embodiment is for full-color display provided with a color filter 160. In this liquid crystal element for full-color display, the suitable range of the scattering gain has to be considered individually for R, G and B, because the scattering characteristics of the polymer-dispersed liquid crystal layer are different at red (R), green (G), and blue (B) wavelengths. In the present embodiment, suitable ranges of the scattering

gain are determined separately for R, G and B, and suitable scattering gains are set separately for R, G and B, so as to obtain a liquid crystal display element with high contrast.

More specifically, when d(μm) is the thickness of the polymer–dispersed liquid crystal layer, and, among the scattering gains for green light in the polymer–dispersed liquid crystal layer, SGr is the scattering gain of the red (R) pixel region 4R, SGg is the scattering gain of the green (G) pixel region 4G, and SGb is the scattering gain of the blue (B) pixel region 4B, then, in the G pixel region 104G:

(Equation 2) $50\exp(-0.4d) < SGg < 360\exp(-0.47d)$ is satisfied,

in the B pixel region 104B:

(Equation 3) $50\exp(-0.4d) < SGb < 360\exp(-0.47d)$ is satisfied,

and in the R pixel region 104R:

(Equation 4) $40\exp(-0.3d) < SGr < 650\exp(-0.4d)$ is satisfied.

These ranges are the ranges of suitable scattering gains, in which a contrast of at least 70% of the maximum contrast can be achieved. The reason for this is explained in the following. First, the range of suitable scattering gains in the G pixel region 104G is given by Equation 2, in correspondence to Equation 1 of Embodiment A1.

In the B pixel region 104B, the range of suitable scattering gains is strictly speaking different from the range of suitable scattering gains for the G pixel region 104G. However, according to the experimental results obtained by the inventors, the range of Equation 3 gives sufficiently suitable values in the B pixel region 104B when taking the same range as for the G

pixel region 104G.

Equation 4 is determined as the suitable range in the R pixel region 104R, from Fig. 11, which shows the relation between scattering gain and panel gap. Fig. 11 has been determined by the same method as in Embodiment A1 and corresponds to Fig. 6.

Consequently, setting the scattering gains in the pixel regions 104R, 104G and 104G to the ranges of these Equations 2 to 4, a reflective liquid crystal display element for full-color display with high contrast can be obtained.

Furthermore, in this embodiment, when rR is the particle diameter of the liquid crystal drops 112R in the R pixel region 104R, rG is the particle diameter of the liquid crystal drops 112G in the G pixel region 104G, and rB is the particle diameter of the liquid crystal drops 112B in the B pixel region 104B, then rR > rG > rB. With this configuration, it is easy to manufacture a liquid crystal display element, in which the Equations 2 to 4 are satisfied. The following explains the reasons for this.

It is known that the relation between the particle diameter of the RGB liquid crystal drops and the scattering gain is as shown in Fig. 12, for a constant panel gap and level of anisotropy of the refractive index. Here, it is assumed that, for example, N1 is the scattering gain of the R pixel region 104R (N1 is a value within the range of Equation 4), N2 is the scattering gain of the G pixel region 104G (N2 is a value within the range of Equation 2), N3 is the scattering gain of the B pixel region 104B (N3 is a value within the range of Equation 3). In that case, the particle diameter rR can be either

rR1 or rR2. Similarly, the particle diameter rG can be either rG1 or rG2, and the particle diameter rB can be either rB1 or rB2. Consequently, for a liquid crystal display element satisfying the Equations 2 to 4, a plurality of combinations for the size of the RGB liquid crystal drops are possible. For those combinations that satisfy rR > rG > rB (for example, rR2 > rG2 > rB2), the manufacturing is easier than for the other combinations. That is to say, it is possible to irradiate UV light from the side of the color filter 160, and when doing so, the color filter 160 weakens the intensity of the UV light in order from the R color filter portion 161 over the G color filter portion 162 to the B color filter portion 163, so that a liquid crystal layer is formed where rR > rG > rB is satisfied. For other combinations, it is necessary to apply such methods as irradiating UV light through separate masks for R, G and B, for example, which makes the manufacturing more troublesome.

<u>More Specific Example of Embodiment A4</u>

The following is an explanation of a more specific example of Embodiment A4.

A liquid crystal display element 101C as shown in Fig. 10 was prepared by the following method. That is to say, it was prepared by basically the same method as Embodiment A1, except that a color filter 160 was formed on the opposing substrate 103 on the opposite side.

Then, the relation between the range of scattering gains that are suitable for attaining high contrast and the panel gap was analyzed for each of the RGB pixel regions by the same method as in Embodiment A1. For

this, the ranges where at least 70% of the maximum contrast are realized were taken as the suitable ranges. As the result, it was determined that, as above, in the G pixel region 104G, a high contrast can be attained when

(Equation 2) $50\exp(-0.4d) < SGg < 360\exp(-0.47d)$ is satisfied.

In the B pixel region 104B, a high contrast can be attained when

(Equation 3) $50\exp(-0.4d) < SGb < 360\exp(-0.47d)$ is satisfied.

In the R pixel region 104R, with the graph from Fig. 12, a high contrast can be attained when

(Equation 4) $40\exp(-0.3d) < SGr < 650\exp(-0.4d)$ is satisfied.

Here, the contrast becomes largest at $SGr = 100\exp(-0.27d)$.

As in Embodiment A1, the contrast in the G pixel region 104G becomes largest at $SGg = 265\exp(-0.5d)$, and the contrast in the B pixel region 104B becomes largest at $SGb = 265\exp(-0.5d)$

Furthermore, the gain was optimized by changing the particle diameter of the liquid crystal drops for R, G and B. More specifically, when rR is the particle diameter of the liquid crystal drops in the R pixel region 104R, rG is the particle diameter of the liquid crystal drops in the G pixel region 104G, and rB is the particle diameter of the liquid crystal drops in the B pixel region 104B, then the liquid crystal drops in each of the R, G and B pixel regions were formed such as to satisfy $rR > rG > rB$. At the wavelengths of R, G and B light, B corresponds to about 430nm, G corresponds to about 540nm, and R corresponds to about 620nm.

Embodiment A5

Fig. 13 is a simplified cross–sectional view of a liquid crystal display element 101D in accordance with Embodiment A5 of the present invention. In this embodiment, elements corresponding to Embodiment A1 are marked with the same reference symbols, and their further explanation has been omitted. Like Embodiment A4, this embodiment is a reflective liquid crystal display element for full–color display. However, in this embodiment, a resin film substrate 103 is used instead of the opposing substrate 103 made of glass.

This embodiment differs from Embodiment A4 in that the thickness of the liquid crystal layer is configured so as to differ in each of the R, G and B pixel regions. Moreover, the cell thicknesses are configured such that the scattering gain in each of the R, G and B pixel regions corresponds to R, G and B.

More specifically, when the layer thickness dR, the layer thickness dG and the layer thickness dB (in μm) are the layer thicknesses corresponding to the R pixel region 104R, the G pixel region 104G, and the B pixel region 104B, and when, among the scattering gains for green light in the polymer–dispersed liquid crystal layer, SGr is the scattering gain of the red (R) pixel region 4R, SGg is the scattering gain of the green (G) pixel region 4G, and SGb is the scattering gain of the blue (B) pixel region 4B, then, in the G pixel region 104G:

(Equation 5) $50\exp(-0.4dG) < SGg < 360\exp(-0.47dG)$ is satisfied,

in the B pixel region 104B:

(Equation 6) $50\exp(-0.4dB) < SGb < 360\exp(-0.47dB)$ is satisfied,

and in the R pixel region 104R:

(Equation 7) $40\exp(-0.3dR) < SGr < 650\exp(-0.4dR)$ is satisfied.

These ranges are ranges of suitable scattering gains, in which at least 70% of the maximum contrast can be realized. Providing the R pixel region, the G pixel region, and the B pixel region of the polymer–dispersed liquid crystal layer 104 with different layer thicknesses in this manner, it is possible to obtain a reflective liquid crystal display element for full–color display with high contrast.

Furthermore, in this embodiment, the layer thicknesses dR, dG and dB satisfy $dR > dG > dB$. With such a configuration, a liquid crystal display element can be obtained, in which the same scattering gain is realized within the suitable regions, because the relation of the layer thickness and the scattering gain for R, G and B is as shown in Fig. 14. As becomes clear from Fig. 14, $dR > dG > dB$ should be satisfied to obtain the same scattering gain for R, G and B. Consequently, by satisfying the Equations 5 to 7 and by satisfying $dR > dG > dB$ in this embodiment, a substantially uniform display contrast is obtained for the R, G and B pixels, in addition to a display with high contrast.

It should be noted that even though this example is configured so as to satisfy $dR > dG > dB$ in order to obtain a substantially uniform display contrast among the various pixels, the present invention is not limited to this, and it is possible to control the contrast in the R, G and B pixels as desired by satisfying the Equations 5 to 7 and changing the layer thickness of the R, G

and B pixels individually.

More Specific Example of Embodiment A5

The following is an explanation of a more specific example of Embodiment A5.

A liquid crystal display element 101D as shown in Fig. 13 was prepared by the following method. A color filter 60 was formed on an array substrate 102 having reflective pixel electrodes 105, 105b and 105c. Then, a peeling material was applied to a glass substrate (not shown in the drawings) having protrusions / recesses corresponding to the R, G and B pixels, and the glass substrate was laminated on the array substrate 102. Then, polymer–dispersed liquid crystal material was injected between the substrates and a polymer–dispersed liquid crystal panel was formed by UV light polymerization. Then, the glass substrate was peeled off at the site of the peeling material. Thus, the polymer–dispersed liquid crystal layer 104 was provided with layer thicknesses that differ for the R, G and B pixels, in correspondence to the protrusions / recesses in the glass substrate. This was done such that layer thickness dB > layer thickness dG > layer thickness dR is satisfied. More specifically, the layer thickness dB was set to 7μm, the layer thickness dG was set to 4μm, and the layer thickness dR was set to 3μm. Then, an insulating film 110 was applied to the polymer–dispersed liquid crystal layer 104, and a resin film substrate 103a having an opposing electrode 109 was layered, thereby obtaining a polymer–dispersed liquid crystal display element. A contrast of 20 to 25 was attained in each of the R,

G and B pixels, and a substantially uniform display contrast was attained.

In this manner, it is possible to control the contrast of the R, G and B pixels as desired by individually changing the R, G and B layer thicknesses. Furthermore, a lighter weight can be attained using a resin film substrate 103a for the opposing substrate. In this example, a glass substrate having protrusions / recesses is used, but it is also possible to form a flat polymer–dispersed liquid crystal layer first, and then press it with a die having protrusions / recesses.

Supplemental Explanations for Embodiment A

In the above embodiments, the scattering gain for green light was used, but there is no limitation to this, and it is also possible to use the scattering gain for white light. The values for the Equations 1 to 7 are substantially the same, regardless whether the scattering gain for white light or for green light is used. It seems that since human sensitivity with regard to white light is determined mainly by the intensity of the green color components, there is substantially no difference between using the scattering gain for white light and the scattering gain for green light.

Also, the liquid crystal display elements in accordance with the present invention are not limited to shapes in which the liquid drops are independently present in the polymer, and they can also be partially linked to one another. Moreover, it is also possible to use a structure, in which the liquid crystal is embedded in a three–dimensional polymer network. Any material can be used for the polymer–dispersed liquid crystal layer, as long

as its scattering display mode is the normally–white mode, using a liquid crystal with positive dielectric anisotropy. Instead of aluminum, the reflective pixel electrode serving as the reflective layer can also be made of chromium or the like, or it can be a dielectric multi–layer film reflector provided with a dielectric layer. Moreover, the reflective pixel electrode can be of flat shape, or it can be provided with a micro–structure, such as a diffraction grating or a saw–tooth shape. Such a structure has the effect of suppressing reflections of ambient light. Moreover, in the Embodiments A1 to A3, the reflective pixel electrodes were prepared on the same plane as the source lines, but it is also possible to form the reflective pixel electrodes, for example, on top of a passivation layer. This has the effect of increasing the numerical aperture of the pixels and the luminance by forming the reflective pixel electrodes on the passivation layer also above source and target.

Embodiment B1

Referring to Figs. 15 to 19, the following is an explanation of a scattering display element in accordance with Embodiment B1 of the present invention. As shown in Fig. 15, this display element is configured by providing a compound layer 225 of a polymer 223 and a liquid crystal 224, serving as a scattering/transmission means, between a pair of substrates 221 and 222 on which transparent electrodes 221a and 222a are formed. A reflector 226 serving as a reflection means is provided on the outer side of the substrate 222.

Substrates made of glass or resin are used for the substrates 221 and

222. Moreover, a polymer–dispersed liquid crystal or a polymer–network liquid crystal, for example, is used for the compound layer 225. In a polymer–dispersed liquid crystal, substantially spherical liquid crystals are dispersed and kept in a polymer (a portion of the liquid crystal drops can also be linked), and in a polymer–network liquid crystal, the liquid crystal is held in a mesh–shaped polymer network in a so–called "continuous mesh structure". Fig. 15 shows an example using a polymer–dispersed liquid crystal. Here, the refractive index n_e of the liquid crystal molecules in the liquid crystal 224 in the long axis direction is set to be the same as the refractive index n_p of the polymer 223, whereas the refractive index n_0 of the liquid crystal molecules in the short axis direction is set to be different from the refractive index n_p, as illustrated schematically in Fig. 16. Moreover, when a voltage is applied between the transparent electrodes 221a and 222a, the liquid crystal molecules are oriented with their long axis along the electric force lines.

As shown in Fig. 17, substantially stripe–shaped protrusions 226a, which are oblong in the vertical direction of the display screen and whose curvature in horizontal direction is larger than the curvature in vertical direction, are formed on the surface of the reflector 226, where they also function as an anisotropic scattering means. That is to say, if the reflection surface of the reflector 226' is mirror finished as in a conventional display element, then incident light is reflected in a specular reflection as shown in Fig. 18(a), whereas in case of the reflector 226 of Embodiment B1, the reflection is somewhat diffused, and the scattering is provided with such

anisotropy that the scattering degree of the reflected light is larger in the horizontal direction than in the vertical direction, as shown in Fig. 18(b).

When no voltage is applied between the transparent electrodes 221a and 222a in a display element configured in this manner, the long axes of the liquid crystal molecules in the liquid crystal 224 are oriented in random directions. In this situation, light that is incident on the compound layer 225, is refracted in various directions when it passes the border between the polymer 223 and the liquid crystal 224. That is to say, scattering occurs because of the mismatch of the refractive indices (scattering state), and a bright display (white display) is attained in which the display screen appears cloudy regardless of the viewing direction. Moreover, the reflector 226 also reflects light that in the compound layer 225 toward the reflector 226, so that this light also contributes to the display, and a display with high luminance is attained.

On the other hand, when a predetermined voltage is applied between the transparent electrodes 221a and 222a, then the liquid crystal molecules in the liquid crystal 224 are oriented such that their long axis direction aligns along the electrical force lines. Since now the refractive indices of the polymer 223 and the liquid crystal 224 in the direction in which light is incident on the compound layer 225 are substantially the same, the light that is incident on the compound layer 225 is transmitted without scattering (transmitting state), diffusively reflected as described above by the reflector 226 so that it is provided with anisotropy, and again transmitted by the compound layer 225. Therefore, as shown in Fig. 19, light–source light

(external light) that is irradiated from a direction indicated by the position P (obliquely in front of the display screen) is diffusively reflected in a direction widening up mainly in the horizontal direction of the display screen, as indicated by the region R in the drawing. Therefore, at the regular viewing range (region Q) of the displayed image, the reflected light–source light does not enter the visual field, and dark display (black display) is achieved reliably. Moreover, when becoming visible in the range beyond the region Q, the luminance decreases due to the scattering of the reflected light–source light, so that a gray-scale inversion does not occur, and the decreasing of the contrast can be kept small, alleviating the impression of an unnatural display.

A bitmap image can be displayed by individually switching each pixel into the scattering state or the transmitting state, depending on whether a voltage is applied between the transparent electrodes 221a and 22a.

To actually drive the display elements, TFTs (thin–film transistors) were used, but the driving method is not limited to this, and an even better contrast could be attained with a driving method applying a bias, in which white is displayed when a certain low voltage is applied, to perform gamma correction.

The surface shape of the reflector 226 is not limited to being provided with substantially stripe–shaped protrusions 226 as described above, and it can also be provided with oval protrusions extending in longitudinal direction. Moreover, it is also possible to provide cracks in the longitudinal direction, or to form semi–cylindrical protrusions. That is to say, a similar

effect can be attained, when the surface face is such that anisotropic scattering is attained, such that the scattering degree of the reflected light in the horizontal direction of the display screen is larger than, for example, the vertical direction.

Furthermore, it is also possible to take a flat plate for the reflector and to form a diffraction grating in the liquid crystal panel. Using a diffraction grating with one–dimensional anisotropy formed in the vertical direction of the display screen instead of having two–dimensionally isotropic characteristics, the same anisoptropic scattering effect as described above could be attained, because horizontal diffraction occurred. It should be noted that such a diffraction grating can be formed near the upper substrate or near the rear side substrate. Also, the diffraction grating can be formed on the substrates using photoresist.

Embodiment B2

Referring to Figs. 20 and 21, the following is an explanation of a scattering display element in accordance with Embodiment B2 of the present invention. In the following, structural elements having the same function as in Embodiment B1 or the other embodiments are marked with the same reference symbols, and their further explanation has been omitted.

As shown in Fig. 20, this display element is provided with a lens sheet film 237 as an anisotropic transmission means on the surface of the substrate 221. As shown in Fig. 21, this lens sheet film 237 is formed with lenticular lenses with uniform thickness in the vertical direction of the

display screen, which act as convex lenses in horizontal direction. Moreover, the reflection plane of the reflector 236 is made flat. It should be noted that instead of providing a reflector 236, it is also possible to make the transparent electrode 222a of a reflective material.

When the compound layer 225 in this configuration is in the transparent state, then, for the reflected light–source light that has been irradiated on the display device, the vertical light path of the display screen is a light path of specular reflection, whereas the horizontal light path widens and disperses due to the lens effect of the lens sheet film 237. As a result, like in the display element of Embodiment B1, reflected light–source light does not enter the visual field in the regular viewing range of the displayed image, and dark display (black display) is achieved. Moreover, gray-scale inversion and substantial decreases of the contrast can be suppressed over a wide visual range.

The lens sheet film 237 is not limited to forming lenticular lenses as described above, and it is also possible to form substantially stripe–shaped protrusions 226a, which are oblong in the vertical direction of the display screen and whose curvature in horizontal direction is larger than the curvature in vertical direction, like the protrusions 226a in the reflector 226 of Embodiment B1.

Embodiment B3

Referring to Figs. 22 to 24, the following is an explanation of a scattering display element in accordance with Embodiment B3 of the present

invention.

In this display element, only the surface shape of the reflector is different from the display element in Embodiment B1. That is to say, as shown in Fig. 22, the cross–sectional shape along A – A of the reflector 246 serving as a reflection means and as an emission angle modification means is sawtooth–shaped, and the normal on the main inclination of the surface is tilted toward the lower side of the display surface.

By providing such a reflector 246, when the compound layer 225 is in the transmitting state, the emission angle β is larger than the incidence angle α of the light–source light that is incident from above the display screen on the display element, as shown in Fig. 23. Therefore, as indicated by position R in Fig. 24, the reflected light–source light is reflected even more downward than by specular reflection when the reflector is flat, which means that it is reflected in a direction that is considerably removed from the regular viewing range of the displayed image, it does not enter the visual field, and dark display (black display) is achieved reliably.

Furthermore, the reflected light could be confined inside the substrate by making the inclination angle of the reflector 246 even larger. Thus, it could be achieved that almost no outgoing light or no outgoing light at all is emitted. That is to say, when the emission angle in the transmitting state is large, in particular when it is larger than the critical angle for total reflection, no more light is emitted. In such a case of total reflection, there is no emission light, so that there is no angle at which the light is emitted from the panel, but as is shown in Fig. 27 explained below,

inside the panel, light is incident on the reflector 246 at an angle γ with respect to the normal on the substrate 222 and is reflected at an angle δ with respect to the normal, so that these angles γ and δ can actually be thought of as the incidence angle and the emission angle. Providing the reflector 246 with inclinations as described above, the emission angle δ becomes larger than the incidence angle γ. Therefore, when the emission angle δ becomes larger than the critical angle for total reflection, the light is reflected completely by the substrates 221 and 222, and propagated within the substrates. In this situation, the light does not leak to the outside. When, for example, the neighboring pixels are in the scattering state, this confined light is scattered by the pixels in the scattering state, and emitted. This effect is very useful as the brightness of the display is increased. When there are no pixels in the scattering state nearby, then the light is attenuated within a few reflections, for example, by a black matrix or a color filter, and finally peters out. It is also possible that a portion of the light reaches an end surface of the liquid crystal element and shines from this end surface, but this can be solved by hiding the end surfaces in a casing.

It should be noted that the surface shape for the reflector 246 is not limited to the sawtooth shape mentioned above, and any shape in which light is reflected such that the emission angle β is larger than the incidence angle α of light–source light incident on the display element from above the display screen is suitable.

Embodiment B4

The following is a more detailed explanation of the inclination angles of the sawtooth shape in a display element with a similar configuration as the scattering display element in Embodiment B3. It should be noted that for illustrative reasons in Fig. 25 and elsewhere, the inclination angle has been schematically drawn somewhat exaggerated.

In this display element, the reflector 246 is provided on the substrate 222 (array substrate) on the side of the compound layer 225, that is, on an insulating layer 248 covering the source line 247a etc. formed on the substrate 222, as shown in Fig. 25, keeping the parallax small. Moreover, a color filter 221b is provided between the substrate 221 (opposing substrate) and the transparent substrate 221a (opposing electrode). In the reflector 246, a reflective layer 246b also serving as a pixel electrode is formed on a sawtooth–shaped resist. The repeat pitch of the sawtooth shape of the reflector 246 is set to, for example, at least 2μm and at most 100μm. Usually, it is difficult to make the repeat pitch smaller than 2μm with regard to manufacturing precision, because then the edges tend to round, whereas if the repeat pitch is larger than 100μm, the level differences in the sawtooth shape becomes large, and the uniformity of the panel gap (that is, the thickness of the compound layer 225) decreases, so that display irregularities tend to occur.

As shown in Figs. 26 and 27, in this display element, the light–source light that is incident at the incidence angle α is emitted at the emission angle β, as has been explained for Embodiment B3, or is confined between the

substrate 221 and the substrate 222. To be more precise, the light–source light is refracted at the substrate 221, is incident on the reflector 246 at an angle γ with respect to the normal on the substrate 222, and is reflected at an angle δ with respect to the normal (when θ is the inclination angle of the reflector 246, then $\delta = 2\theta + \gamma$). This reflected light is again refracted by the substrate 221 and emitted at an emission angle β ($\beta > \alpha$) (Fig. 26), or, if the inclination angle θ of the reflector 246 is relatively large and the angle δ is larger than the critical angle for total reflection of the substrate 221, totally reflected by the substrate 221 and reflected again by the reflector 246 so that it is propagated between the substrate 221 and the reflector 246 at an ever deeper angle and confined between the substrate 221 and the substrate 222 (Fig. 27). (It should be noted that for illustrative purposes, for example, the insulating layer 248 is not shown in Figs. 26 and 27.)

Referring to Figs. 28 and 29, the relation between the incidence angle α, the emission angle β, and the inclination angle θ of the reflector 246 is explained in more detail. Fig. 28 shows the relation of the incidence angle α and the emission angle β for various inclination angles θ of the reflector 246, and Fig. 29 shows the relation of the inclination angles θ of the reflector 246 and the emission angle β for various incidence angles α.

This kind of display element is normally used such that the incidence angle α of the light–source light is about 30°. As becomes clear from the drawings, the emission angle β of the reflected light can be made at least about 50°, by setting the inclination angle θ to at least 5°, so that a display element having superior display characteristics such as a wide viewing angle

and high luminance and contrast can be obtained.

If the inclination angle θ is set to 15°, the emission angle β of reflected light becomes about 80° for a 30° incidence angle α of light–source light. This means that when viewed from a direction at a polar angle of 80°, gray-scale inversion occurs because reflected light–source light enters the visual field, but such viewing directions are far away from the regular viewing direction, so that this does not become a problem in actual use. On the other hand, when viewing from a direction at a polar angle of 30°, the reflected light does not enter the visual field, as in the case of a flat reflector, so that gray-scale inversion does not occur, and a display with a superior image quality without glittering can be obtained.

When the inclination angle θ is set to about 15° or more, the emission angle β can be made about 50° or more for all incident light with an incidence angle α of at least 0°, and when the inclination angle θ is set to 10°, the emission angle β can be made about 30° or more.

Therefore, it is preferable that the inclination angle θ of the reflector 246 is set to at least 5°, more preferably at least 10°, so that the reflected light–source light does not enter the visual field so easily.

Furthermore, when the inclination angle θ is set, for example, to at least 18°, then the theoretical emission angle β for reflected light–source light that is incident at an incidence angle α of about 30° becomes at least 90°, as indicated by the dashed line in Figs. 28 and 29, the reflected light is totally reflected by the substrate 221 as shown in Fig. 27, and confined between the substrate 221 and the substrate 222. In this manner, the

larger the inclination angle θ is, the smaller are the incidence angles α of the incident light for which confinement of the emission light can be effected.

Thus, the larger the inclination angle θ of the reflector 246 is, the larger is the emission angle β, and the less reflected light–source light enters the visual field, but on the other hand, when the inclination angle θ is too large, then the influence of scattering light due too light reflected at the edge portions (that is, substantially vertical portions or portions with steep inclination) of the sawtooth shape in the reflector 246 becomes large, so that there is the danger that the contrast diminishes instead. Therefore, to prevent this diminishing of the contrast due to scattering light, it is preferable that to set the inclination angle θ to at most 30°, more preferably to at most 25°, and even more preferably to at most 15°. It should be noted that to reduce the scattering light as described above, it is also possible to let the edge portions of the sawtooth shape absorb incident light, or, by not forming the reflective layer 246b on the edge portions, let the edge portions transmit incident light, so that the incident light is deviated to the rear side of the reflector 246.

Thus, to make it harder for reflected light–source light to enter the visual field, and to prevent the diminishing of contrast due to scattering light, it is preferable to set the inclination angle θ of the reflector 246 to at least 5° and at most 30°, more preferably to at least 5° and at most 15°, and within this range, the inclination angle θ should be set according to the desired direction of the reflected light–source light, that is, in accordance with such characteristics as the viewing angle.

Embodiment B5

The following is an explanation of an example of a display element configuration, in which the reflective layer 246b does not also serve as the pixel electrode as in Embodiment B4, but also serves as the opposing electrode.

As shown in Fig. 30, in this display element, a reflective layer 265b also serving as the opposing electrode is vapor deposited on a sawtooth–shaped film substrate 265a as the opposing plate 265. Moreover, a transparent pixel electrode 268, a color filter 269 provided at a region substantially corresponding to the transparent pixel electrode 268, and a source line 247a are formed on an array substrate 267.

The sawtooth–shaped film substrate 265a of the opposing substrate 265 is provided with a sawtooth shape having inclined faces with an inclination angle θ of 10°. However, the inclination angle θ is not limited to 10°, and, as explained for Embodiment B4, it should be set in accordance with such characteristics as the desired viewing angle, and both wider viewing angle and increased luminance can be attained by setting it to at least 5° and at most 30°. Such a sawtooth–shaped film substrate 265a can be formed easily, for example, as described in Embodiments B18 and B19 described below, but there is no limitation to this, and various methods can be applied to form the protrusions and recesses of the sawtooth shape.

In a display element configured like this, the emission angle for light that is incident at an incidence angle of, for example, 30° was about 62°.

Therefore, as has been explained for Embodiment B4, when viewing from a regular viewing range (for example, from a direction within a polar angle of 50°), the reflected light–source light does not enter the visual field, so that gray-scale inversion does not occur, and a display with a superior image quality is obtained. Moreover, the display element can be easily made lighter, because a film substrate is used for the opposing substrate 265.

It should be noted that in this example, the color filter 269 is shown to be formed on the side of the array substrate 267, but it is also possible to form it on the side of the opposing substrate 265. Moreover, it is also possible to form the color filter 269 not only in the region substantially corresponding to the transparent pixel electrode 268, but in regions outside of the transparent pixel electrode 268, within the red, green and blue pixel region.

Furthermore, the configuration reflecting incident light at the opposing substrate 265 as described above, can also be applied to Embodiment B1, for example.

<u>Embodiment B6</u>

The following is an explanation of an example of a scattering display element as in the above configuration, in which the sawtooth shape is provided with a random pitch.

In this display element, as shown for example in Fig. 31, the pitch of the sawtooth shape with which the reflector 246 is provided is set to random values within a range of at least 5μm and at most 20μm (so that the pitch of

adjacent sawtooth shapes is mostly different). Moreover, the inclination angle of the sawtooth shapes is set to 15°.

In addition to the effect of preventing, for example, gray-scale inversion by enlarging the emission angle of the reflected light as in Embodiment B3, this configuration suppresses the diffraction of light reflected at the reflector 246, so that a deterioration of the image quality can be prevented. To attain this effect of suppressing diffraction, it is preferable that that the pitch of the sawtooth shape is set to at least 5μm and at most 100μm, and as diffraction usually occurs more easily at smaller pitches (closer to the wavelength of the light), such a suppression of diffraction is particularly effective. That is to say, an image of superior image quality can be displayed even when setting a small pitch. As the pitch is becomes large, diffraction occurs less readily, but when the pitch becomes about 100μm, the pitch becomes visible, so that the image quality tends to deteriorate. Moreover, the pixel size is usually less than 100μm, so that a pitch of 100μm or more also may lead to a lower resolution. Furthermore, when the pitch is large, the level difference in the sawtooth shape becomes large too, and the uniformity of the panel gap (that is, the thickness of the compound layer 225) decreases, so that display irregularities tend to occur. For the same reason, it is preferable that the pitch range (that is the difference between largest pitch and smallest pitch) is not more than 30μm, more preferably not more than than 20μm.

The inclination angle of the sawtooth shape is not limited to 15°, and it can be set to various values within a range of, for example, 5° to 30°. It is

also possible to set the inclination angle at random, that is, to set a different inclination angle for each sawtooth shape. More specifically, it is possible to set an inclination angle distribution of, for example:

5°: 5%, 10°: 40%, 15°: 40%, 20°: 5%. When the inclination angle is small, the viewing range becomes narrow, but the white luminance seen from the viewing angle (for example, from 15°) becomes large. On the other hand, when the inclination angle is large, the viewing range is large, but the white luminance for a 15° viewing angle becomes low. By providing locations with different inclination angles, it is possible to adjust the viewing range and the white luminance as desired.

Embodiment B7

The following is an explanation of an example of a display element, in which, like in Embodiment B3, the emission angle of light–source light is made large, and in which scattering occurs also in the horizontal direction of the display screen.

As shown in Figs. 32 and 33, the reflector 249 with which this display element is provided is segment–shaped, semi–circular or partially circular when seen from a direction perpendicular to the display screen, and the reflective layer 249b is formed on a protruding resist 249a whose surface is substantially spherical (that is, substantially partially spherical) or partially elliptical. For each pixel region that is enclosed by source lines 247a and gate lines 247b, a plurality of such protruding resists 249a of 2μm height are arranged in a cluster at a pitch of 40μm in vertical direction of the display

screen. In these protruding resists 249a, the inclination angle in the cross–section shown in Fig. 33 is set to at least 5° and at most 30°.

With this configuration, incident light following a light path that is inside the substantially symmetric plane of shapes of the protruding resists 249a (that is, the plane of the cross–section along A – A in Fig. 32) is emitted at an emission angle that is larger than the incidence angle toward the lower side of the display screen, as in Embodiment B3 for example, so that gray-scale inversion is prevented when viewing, for example, from a direction as indicated by the arrow P in Fig. 33. Moreover, incident light with a lightpath or direction that is not in this symmetry plane is emitted largely toward the lower side of the display screen and in horizontally scattered directions. Therefore, the amount of reflected light can be kept low also when viewing from other directions than the arrow direction P, so that gray-scale inversion can still be reduced, and consequently a broader viewing angle can be attained.

Instead of aligning the protruding resists 249a as described above, they can also be arranged at random.

Moreover, the shape of the protruding resists 249a is not limited to partially spherical as above, and it may also be the shape of the lower portions (with respect to the display screen) of the substantially spindle–shaped or elliptical shapes of the protrusions 226a of Embodiment B1 (Fig. 17), as shown for example in Fig. 34. In this case, reflected light is emitted largely toward the lower side of the display screen, and in directions with large horizontal scattering.

Embodiment B8

Referring to Figs. 35 and 36, the following is an explanation of a scattering display element in accordance with Embodiment B8.

In this display element, only the cross–sectional shape of the lens sheet film is different from the display element in Embodiment B2. That is to say, the lens sheet film 257 serving as a refraction/transmission means is formed to a shape where only the upper half of convex lenses or rod lenses are lined up in the cross–sectional shape along cross–section A – A as shown in Fig. 35.

As shown in Fig. 36, providing such a lens sheet film 257 makes the emission angle β larger than the incidence angle α of light–source light incident on the display element when the compound layer 225 is in the transmitting state, like in the display element of Embodiment B3, and the reflected light–source light is reflected in a direction away from the viewing range of the displayed image, or it is not reflected at all, so that it does not enter the visual field, and dark display (black display) is achieved reliably.

Moreover, the cross–sectional shape of the lens sheet film 257 is not limited to the half–convex lens shapes mentioned above, and it is also possible to use any shape with which light–source light is refracted in a direction where the emission angle β is larger than the incidence angle α of light–source light that is incident on the display element from an upper side of the display screen, such as a prism for example.

Embodiment B9

Referring to Figs. 37 and 38, the following is an explanation of a scattering display element in accordance with Embodiment B9.

In this display element, only the reflector is different from the display element in Embodiment B1. That is to say, the reflector 266 serving as a reflection means and as an emission angle modification means has a retroreflector structure as shown in Fig. 37, and regardless from which direction light is incident, it is reflected in a direction that is the same as this incidence direction.

As shown in Fig. 38, using such a reflector 266, light–source light that is incident from the direction indicated by position P when the compound layer 225 is in the transmitting state is reflected back in the same direction, as indicated by position R. Therefore, the reflected light–source light does not enter the visual field in the viewing range of the displayed image. This means that except for very unusual usage conditions, no light source will be located in the viewing direction (and if there is a light source in such a direction, the observer will cast a shadow), so that reflected light–source light does not enter the visual field, and dark display (black display) is achieved reliably.

It should be noted that for the reflector 266, it is possible to take a plate utilizing total reflection, or to form a reflective layer, such as a metal film. It is also possible to use a plate having the property of reflecting light into roughly the same direction as the incoming direction, instead of a plate having a retroreflector structure in the narrow sense.

Embodiment B10

Also when using a dispersive film as an attenuation means without anisotropic scattering properties instead of the lens sheet film 237 in Embodiment B2, it is possible to reduce the amount of reflected light–source light, and to keep the diminishing of the contrast in the displayed image at a low level by setting the transmissivity of the dispersive film to a predetermined value. Here, the "transmissivity" is defined as the ratio of the total amount of incident light minus the total amount of light that returns to the hemisphere of the light source to the total amount of incident light.

It could be confirmed that by setting the transmissivity to not more than 95%, the amount of light–source light reflected by specular reflection from the reflector 236 when the compound layer 225 is in the transmitting state can be reduced, and the diminishing of the contrast of the displayed image can be suppressed. However, when the transmissivity is lower than 50%, the amount of light scattered and reflected at the upper surface of the dispersive film and entering the visual field increases, so that the contrast of the displayed image decreases instead. A superior contrast can be attained by setting the transmissivity to 50 – 95%, preferably to 70 – 95%. Furthermore, for the same reason as when the transmissivity is too low, it is preferable that the dispersion intensity of the dispersive film is low.

For such a dispersive film, a strict optical design as for the lens sheet film 237 of Embodiment B2 is not possible, so that the viewing angle

deteriorates slightly, but in practice, a sufficient effect could be confirmed. Moreover, a dispersive film is cheaper than the lens sheet film 237, so that the display properties of the display element can be improved while reducing the manufacturing costs.

Embodiment B11

Instead of the reflector 226 in Embodiment B1, it is also possible to use half mirrors 276 to 278 as shown in Fig. 39 as the reflection means and attenuation means.

The half mirrors 276 and 277 in Figs. 39(a) and (b) are made by forming reflective films 276b and 277b provided with reflectivity and transmissivity on a black substrate 276a or a transparent substrate 277a respectively. The half mirror 278 in Fig. 39(c) is made by layering a transparent substrate 278a, a flat reflecting film 278b, and oblique reflective films 278c.

Using the half mirror 276, the reflectivity is low, so that when the compound layer 225 is in the scattering state, the luminance for bright display (white display) decreases (although the attained luminance is higher than in conventional display elements not provided with a reflector), but the amount of specularly reflected light–source light for dark display (black display) when the compound layer 225 is in the transmitting state decreases as well, so that the contrast can be increased.

More precisely, the amount of display light for bright display and the amount of specularly reflected light for dark display when for example the

reflectivity of the half mirror 276 is 50% and taking the amount of light–source light as 1 is as shown in Table 1 below.

That is, for bright display, 1/2 of the incident light is scattered and reflected on the surface side by the compound layer 225 and emitted, whereas the 50% of the remaining light ($1/2 \times 1/2 = 1/4$) that is scattered and transmitted to the side of the half mirror 276 is reflected by the half mirror 276 and emitted. As a result, a total of $1/2 + 1/4 = 3/4$ serves as display light. In conventional display elements without reflectors, only the light that is scattered and reflected on the surface side serves as display light, so that the display light is 1/2, and in display elements having a reflector of 100% reflectivity, all of the scattered and transmitted light is reflected and emitted, so that the display light is $1/2 + 1/2 = 1$.

For dark display, when the light–source light is incident from an oblique direction on the display surface, the amount of specularly reflected light varies depending on the polarization of the incident light. First of all, for the components polarized vertically with respect to the display surface (components polarized in long axis direction of the liquid crystal molecules), the refractive index of the liquid crystal molecules is between the refractive index n_e for the long axis direction and the refractive index n_0 for the short axis direction, so that the incident light is scattered to a certain degree. Denoting the portion that is scattered as α and the portion that is not scattered but transmitted as $1 - \alpha$, the amount of specularly reflected light is $1/2 \times (1 - \alpha) \times 1/2 = (1 - \alpha)/4$, because the component of the incident light that is polarized as described above is 1/2, and the reflectivity of the half

mirror 276 is 50%. Such scattering does not occur for the components polarized in parallel to the display surface (components polarized in short axis direction of the liquid crystal molecules), so that the amount of specularly reflected light is $1/2 \times 1/2 = 1/4$. Consequently, the total amount of specularly reflected light is $(1 - \alpha)/4 + 1/4 = (2 - \alpha)/4$. In conventional display elements without reflectors, incident light-source light is not reflected, so that the amount of specularly reflected light is 0, and in display elements having a reflector of 100% reflectivity, the amount of specularly reflected light of the two polarization component is $(1 - \alpha)/2$ and 1/2 respectively, so that the total is $(2 - \alpha)/2$.

Determining the ratio between the amount of specularly reflected light and the amount of display light, this ratio is $(2 - \alpha)/3$ when using the half mirror 276, 0 when using no reflector, and $(2 - \alpha)/2$ when using a reflector with 100% reflectivity. Consequently, using the half mirror 276, a higher luminance can be attained than when using no reflector, and a higher contrast can be attained than with a reflector of 100% reflectivity.

Table 1

	polarization with respect to display screen	incident light	conventional display element		display element of the present invention	
			without reflector	with reflector	reflector (50% reflectivity) (Embodiment 7)	reflector + polarizer (Embodiment 9)
A: display light for scattering state (bright/white display)	perpendicular	1/2	1/4	1/2	3/8	3/8
	parallel	1/2	1/4	1/2	3/8	3/8
	total	1	1/2	1	3/4	3/4
B: specularly reflected light for scattering state (bright/white display)	perpendicular	1/2	0	$(1-\alpha)/2$	$(1-\alpha)/4$	$(1-\alpha)/4$
	parallel	1/2	0	1/2	1/4	0
	total	1	0	$(2-\alpha)/2$	$(2-\alpha)/4$	$(1-\alpha)/4$
B/A			0	$(2-\alpha)/2$	$(2-\alpha)/3$	$(1-\alpha)/3$

On the other hand, using the half mirror 277 so that external light can also be incident from the rear side of the display element, a portion of this external light from the rear side reaches the visual field during both bright display and dark display, so that the contrast decreases somewhat, but a bright display image can be obtained.

Furthermore, using the half mirror 278, the scattered light transmitted by the reflecting film 278b is reflected by the reflecting films 278c during bright display, so that a higher luminance than with the half

mirror 276 can be attained, and during dark display, the light–source light transmitted by the reflecting film 278b is reflected by the reflecting films 278c in a direction away from the viewing range of the displayed image, so that this light does not enter the visual field, and a high contrast can be attained.

It should be noted that the half mirrors 276 to 278 do not necessarily have to have a transmissivity of 50%, and it is sufficient if they have reflectivity and transmissivity. A particularly good display image quality can be attained if the reflectivity is preferably not more than 90%, more preferably not more than 80%. Furthermore, there is no limitation to forming the reflective film 276b on a black substrate 276a, and it is also possible to form the reflective film 276b on the substrate 222 or to provide the transparent electrode 222a with reflectivity and transmissivity.

Here, "reflectivity" is defined as the ratio of the total amount of light reflected into the hemisphere of the light source to the total amount of incident light.

Embodiment B12

Instead of the half mirrors 276 to 278 of Embodiment B11, it is also possible to use a thin film made of chromium formed, for example, by vapor deposition on the substrate as the reflection means and attenuation means. Furthermore, it is also possible to make the transparent electrode 222a of chromium. Compared to materials with high reflectivity, such as aluminum or silver, which are commonly used for reflectors, chromium has a relatively

high light absorbance, and a low reflectivity, so that only a portion of the incident light is reflected. This means that the same effect as with the half mirror 276 of Embodiment B11 can be attained.

It should be noted that there is no limitation to chromium, and any material having a relatively low reflectivity is suitable. In particular, it could be confirmed that when the reflectivity is not more than 90%, preferably not more than 80%, a display image with superior contrast can be attained by reducing the amount of specularly reflected light–source light. It is also possible to use for example a gray plate having the above–mentioned reflectivity as the reflector.

Embodiment B13

The following is an explanation of a scattering display element in Embodiment B13 of the present invention, in which a polarizer is provided as a polarization means on the upper surface of the reflector.

As shown in Fig. 40, instead of the reflector 226 of Embodiment B1, this display element includes a polarizer 281 adhered to the substrate 222, as well as a reflector 282 and a protective resin layer 283. The polarizer 281 transmits light components that are polarized in the vertical direction of the display screen and absorbs light components that are polarized in the horizontal direction.

With this configuration, the amount of display light and the amount of specularly reflected light is as shown in Table 1. That is to say, when the compound layer 225 is in the scattering state, only one polarization

component of the scattered light is transmitted by the polarizer 281 and reflected by the reflector 282, so that the amount of display light is 3/4, similar to the case when a reflector of 50% reflectivity is provided. On the other hand, regarding the amount of specularly reflected light when the compound layer 225 is in the transmitting state, when the light–source light is incident on the display screen from an oblique direction, light components that are polarized perpendicularly to the display screen (light components that are polarized in the vertical direction of the display screen) are transmitted through the polarizer 281, so that the amount of specularly reflected light is $(1 - \alpha)/4$, similar to the case when a reflector of 50% reflectivity is provided, and the light components that are polarized in parallel to the display screen (light components that are polarized in the horizontal direction of the display screen) are absorbed by the polarizer 281, so that their amount of specularly reflected light is zero.

Consequently, the total amount of specularly reflected light is $(1 - \alpha)/4$, the ratio between the amount of specularly reflected light and the amount of display light is $(1 - \alpha)/3$, and compared to a display element provided with a reflector of 50% reflectivity, a display image with the same luminance and greater contrast can be attained.

If the incident direction of the light–source light and the orientation of the polarizer 281 is different from the above, then the contrast decreases slightly, but the contrast is still larger than when a reflector of 50% reflectivity is used.

Furthermore, the polarizer 281 can also be provided on the upper

surface of the substrate 221, and although in this case the amount of display light decreases, the contrast is still larger than when a reflector of 50% reflectivity is used.

Embodiment B14

As shown in Fig. 41, in the above embodiments, it is also possible to form a smoothing layer 293 made of a resin on the substrate 291, and a reflective electrode 294 on the smoothing layer 293. Especially when a substrate 291 provided with thin film transistors (TFT) 92 is used, it is possible to prevent unevenness in the reflective electrode 294 due to the influence of the TFT 292 with this configuration, and the reflective electrode 294 easily can be provided with the desired surface shape. Furthermore, the reflective electrode 294 functions as a reflector, so that the parallax caused by the thickness of the substrate 291 is prevented, and the definition of the displayed image easily can be increased. Also, the incident light is reflected by the reflective electrode 294 at the position of the TFT 292, which increases the numerical aperture and increases the luminance even further.

The smoothing film 293 and the reflective electrode 294 can be formed, for example, as follows:

(1) The smoothing film 293 made, for example, of an acrylic resin is formed by spreading it over the substrate 291. If the smoothing layer 293 is made from a black resin, it can be provided with the same function as the black substrate 276 of Fig. 39(a).

(2) To make a display element as in the Embodiments B1, B3 to B7, or

B9, the smoothing film 293 is subjected to a pressing step before the curing, while it is still soft, whereby the desired surface shape (unevenness) can be attained. Thus, complicated shapes can be formed relatively uniformly, and the angular distribution can be controlled precisely, so that the ideal shape can be formed.

To make the reflective electrode 294 scattering, it is also possible to form regions 297a corresponding to the pixels with the patterns shown in Fig. 42, and to make the inclination angle slightly different in each region 297a. In this case, the pattern for the regions 297a is not limited to the above, but it is preferable that the regions 297a are provided with a different inclination angle for each pixel, and that the pattern is the same for each pixel.

(3) A contact hole for connecting the TFT 292 and the reflective electrode 294 is formed by photochromism and etching.

(4) The reflective electrode 294 is formed, for example by vapor deposition, on the smoothing layer 293.

Embodiment B15

The following is an explanation of another configuration and method for making the reflective electrode 294 of Embodiment B14 scattering.

As shown in Fig. 43, in this display element, glass micro–particles 295 of 0.1 to 1 μ m diameter are mixed into the smoothing film 293 made of an acrylic resin. Thus, the surface of the smoothing film 293 is made slightly uneven, and consequently the reflective electrode 294, too, is of uneven shape, and therefore scattering. It is preferable that the glass

micro–particles 295 are present at a density of several to several dozen per pixel, because in that case, a superior contrast can be attained. It should be noted that the smoothing layer and the micro–particles are not limited to those described above.

Moreover, to provide anisotropic scattering, as in the display element of Embodiment B1, it is possible to mix particles shaped ovally or like short fibers instead of the glass micro–particles 295 into a resin with relatively high flowability, and after applying this mixture on the substrate 291, provide the particles with directionality by subjecting the substrate 291 to oscillation, standing the substrate 291 upright, or blowing air over the resin film.

Embodiment B16

The following is an explanation of yet another method for making the reflective electrode 294 of Embodiment B14 scattering.

(1) As shown in Fig. 44(a), an acrylic resin layer 296 is formed, for example, by spreading it over the substrate 291. The TFT 292 has been omitted from Fig. 44(a).

(2) The resin film 296 is patterned as shown in Fig. 44(b) by etching with photolithography, and partitioned for example in stripes.

It should be noted that it is also possible to form the resin layer 296 on the substrate 291 for example by printing, so that it is already patterned.

(3) The resin layer 296 is heated and made soft, so that the cross–section is rounded by so–called heat sagging as shown in Fig. 44(c).

(4) By forming a reflective film on the resin layer 296, a reflective electrode having scattering properties depending on the afore–mentioned patterning and heat processing is formed. That is to say, in the case of a stripe pattern as described above, a reflective electrode 294 with anisotropic scattering (having a reflection angle distribution) is formed.

With this method, it is possible to form a scattering reflective film without using a die or the like.

Furthermore, there is no limitation to the above reflective electrodes, and it is also possible to form the reflector 226 of Embodiment B1 like this.

Embodiment B17

The following is an explanation a method for forming the reflector 246 of the above–described Embodiment B3, for example.

(1) As shown in Fig. 45(a), a resin layer 298 made of acryl of, for example, 0.5μm to 10μm thickness is formed on a substrate 290. The thickness of the resin layer 198 can be chosen in accordance with the inclination angle of the formed reflecting surface, for example.

(2) As shown in Fig. 45(b), a protective film 299 of a predetermined pattern, such as stripes, is formed by applying, exposing and developing a photoresist.

(3) As shown in Fig. 45(c), sandblasting or dry etching is performed from an oblique direction, and the resin layer 298 is eliminated from the portions where no protective film 299 is provided. To be specific, a surface shape with non–symmetric recesses and protrusions as shown in Fig. 45(c) is

formed, because much of resin layer 298 at the portions that are not hidden by the protective film 299 is eroded by blasting it with hard micro–particles from an oblique direction.

Here, sandblasting is appropriate to form relatively large surface shapes, whereas dry etching is appropriate to form fine surface shapes.

(4) Then the protective film 299 is eliminated as shown in Fig. 45(d), and a reflective film is formed for example by vapor deposition of aluminum, thereby forming a reflector 246 having a sawtooth–shaped cross–section, as shown in Fig. 22.

It should be noted that there is no limitation to saw–tooth shapes, and that a variety of cross–sections can be formed by varying the pattern of the protective film 299 or the direction of the sandblasting and by repeating these steps. Furthermore, it is also possible to use a resin with high transparency, such as an acrylic resin, and form a lens sheet film 257 as shown in Fig. 35, without forming a reflective film. A lens sheet film 257 formed in this manner has a relatively rough surface, and is both refracting and scattering, so that it is suitable for cases, in which the direction of the specularly reflected light is to be changed by the refraction, and the light amount is to be reduced by the scattering.

<u>Embodiment B18</u>

The following is an explanation of another method for forming a reflector as in the above–described Embodiment B3, for example.

(1) As shown in Fig. 46(a), an insulating layer 248 of 1.5μm thick SiO_2 is

formed on the substrate 222 provided with the source line 247a etc., and a photosensitive positive resist (S1811 by Shipley Far East, Inc.) is applied in 2μm thickness on the insulating layer 248 and prebaked at a predetermined temperature for a predetermined time to form a first resist layer 261. Then, a first mask 262 in which band–shaped light–blocking portions of 4μm width are formed at 10μm pitch is placed on the first resist layer 261, and the first resist layer 261 is exposed with UV light.

(2) As shown in Fig. 46(b), the first resist layer 261 is developed with a developer (MF926 by Shipley Far East, Inc.) to form a diffraction grating, and then a pattern 261' of hardened stripes of 2μm height and 5μm width with tails (oblique faces) on both sides is formed by heating (annealing) to 180°C for one hour.

(3) As shown in Fig. 46(c), a photosensitive resist (S1811 by Shipley Far East, Inc.) is again applied in 3μm thickness on top of the stripe pattern 261' to form a second resist layer 263.

(4) As shown in Fig. 46(d), the second resist layer 263 is exposed with UV light through a second mask 264. In the second mask 264, band–shaped light–blocking portions of 6μm width – that is, broader than the width in the first mask 262 – are formed at 10μm pitch, and the second mask 264 is placed such that 2μm wide portions near the edges in the stripe pattern 261' are covered.

(5) As shown in Fig. 46(e), the second resist layer 263 is developed and heated as in (2) above, forming a sawtooth–shaped resist 246a.

(6) As shown in Fig. 46(f), a reflector 246 with a sawtooth–shaped

cross–section is made by forming a reflective layer 246b by vapor deposition of aluminum on the entire surface of the sawtooth–shaped resist 246a. Here, it is also possible to form the reflective layer 246b after forming contact holes in the sawtooth–shaped resist 246a, in order to contact the reflective layer 246b and TFT (thin film transistor) elements (not shown in the drawing) provided on the substrate 222. Furthermore, it is also possible to deposit the aluminum not on the entire surface of the sawtooth–shaped resist 246a, and to leave the edge portions of the sawtooth shapes (that is, the almost vertical portions and the portions where the inclination is steep) open. In this case, the contrast can be improved even more, because when the transparent sawtooth–shaped resist 246a is exposed at these edge portions, the scattered light at these edge portions is transmitted into the sawtooth–shaped resist 246a, and can be deviated to the rear side of the reflector 246.

(7) To manufacture a reflective liquid crystal display element having a polymer–dispersed liquid crystal layer using a substrate 222 on which a reflector 246 is formed, as shown for example in Fig. 25, the substrate 222 and the substrate 221 provided with the transparent electrode 221a are laminated together leaving a gap (panel gap) of 5μm, such that the horizontal direction in Fig. 46 becomes the vertical direction of the display screen, and after injecting a polymer–dispersed liquid crystal material (for example, PNM201 by Dainippon Ink and Chemicals, Inc.) into the gap by vacuum injection, UV light is irradiated to polymerize the polymer 223, and separate the phases of polymer 223 and liquid crystal 224.

When the cross–section of a reflector 246 formed in this manner was observed under an electron microscope, a reflection layer having an approximately sawtoothed shape with an inclination angle of 10° was formed. That is to say, it easy to form a non–symmetric cross–sectional shape, such as an approximately sawtoothed shape, by layering two layers of stripe patterns having tails, wherein the layers are shifted against each other.

It should be noted that during the exposure and the developing of (4) and (5), it is also possible to leave the stripe pattern 261' and the second resist layer 263 on the stripe pattern 261' entirely, and when the other portions of the second resist layer are eliminated, such that at least portions of the second resist layer 263 remain that are non–symmetric with respect to the stripe pattern 261', then a non–symmetric cross–sectional shape can be formed.

Furthermore, in the exposure step of either one or both of (1) and (4), it is also possible to irradiate the UV light from an oblique direction, as shown for example in Fig. 47. In that case, it is easier to control the inclination angle and the shape of the sawtooth shape.

Furthermore, there is no limitation to the two–layered stripe pattern described above, and it is also possible to layer more than two layers. In that case, it is easier to control the inclination angle and the shape of the sawtooth shape.

Furthermore, the thickness of the resist layer and the width and pitch of the light–blocking portions in the mask are not limited to the above, and can be chosen in accordance with the viewing angle characteristics of the

display element.

Furthermore, when a mask is used, in which a pattern of exposure holes as shown in Fig. 32 is formed instead of the stripe–shaped light–blocking portions, then it is possible to form the protruding resists 249a as shown for Embodiment B7.

Furthermore, there is no limitation to forming the second resist layer 263 on the entire stripe pattern 261' and substrate 222, and it is possible to form it on only a portion of the stripe pattern 261' or to form it on a portion or all of the stripe pattern 261' and a portion or all of the substrate 222. That is to say, it is easy to form a non–symmetric cross–sectional shape by forming the stripe pattern 261' and the second resist layer 263 shifted relatively against each other.

Embodiment B19

The following is an explanation yet another method for forming a reflector as in the above–described Embodiment B3, for example.

(1) As shown in Fig. 48(a), an insulating layer 248 and a first resist layer 261 are formed on a substrate 222 provided with the source line 247a etc., as in (1) of Embodiment B18, and first resist layer 261 is exposed with UV light through a first mask 262 in which band–shaped light–blocking portions of predetermined width and pitch are formed.

(2) As shown in Fig. 48(b), a stripe pattern 261' with tails (oblique faces) on both sides is formed by developing (wet etching) and heating the first resist layer 261, as in (2) of Embodiment B18.

(3) As shown in Fig. 48(c), dry etching by irradiation of an argon beam is performed, using a second mask 264 covering approximately half of the stripe pattern 261'. Thus, as shown in Fig. 48(d), the approximately half portions of the stripe pattern 261' that were not covered by the second mask 264 are eliminated, and sawtooth–shaped resists 246a enclosed by a tail and a substantially vertical wall are formed.

(4) As shown in Fig. 48(e), a reflective layer 246b is formed by vapor deposition of aluminum on the entire surface of the sawtooth–shaped resists 246a, thereby forming a reflector 246 having a sawtooth–shaped cross–sectional shape.

In this manner, it is possible to form a stripe pattern having tails on both sides, by exposure, developing, and heating, and to form a reflective layer with sawtooth shape by substantially vertically eliminating one half of the tails by dry etching.

In the above–described embodiments, examples were given, that used a compound layer 225 of a polymer 223 and a liquid crystal 224, for example a polymer–dispersed liquid crystal or a polymer–network liquid crystal, but there is no limitation to this, and the same effects can be also attained with a scattering display element in which display is carried out by switching between a scattering state and a transmitting state, controlling the presence of an ac voltage on the liquid crystal, for example.

Also, when a half mirror is used as in Embodiment B11, or a layer having some transparency is used for the black substrate 276a, then it is

possible to provide a back-light unit on the rear side of the display element to make a so-called half-transmitting display element, in which the back light is lit during bright display, and put out to reduce the power consumption, performing display with external light only.

It is also possible to combine several of the afore-mentioned embodiments. In particular, it is possible to form the reflector 226 of Embodiment B1 as a half mirror like in Embodiment B11, and to provide the polarizer 281 of Embodiment B13, so as to lower the light amount by scattering and reducing the reflectivity of specularly reflected light.

It is also possible to provide color filters to display color images.

Referring to the drawings, the following is an explanation of an Embodiment C of the present invention. With this Embodiment C, the luminance and the contrast can be increased by appropriately setting the driving voltage.

Outline of Embodiment C

Fig. 49 is a simplified cross-sectional view of a liquid crystal display device in accordance with Embodiment C. The liquid crystal display device 301 in accordance with this embodiment is a reflective liquid crystal display device. This liquid crystal display device 301 includes a lower substrate 302, an upper substrate 303 arranged in opposition to the lower substrate 302, a reflector 304 made of aluminum, and a liquid crystal layer 305 disposed between the reflector 304 and the upper substrate 303. This liquid crystal

layer 305 is configured as a scattering liquid crystal, performing display by switching between a scattering state and a transmitting state. Examples for such a scattering liquid crystal are polymer–dispersed liquid crystals, dynamic scattering mode (DSM) liquid crystals, and cholesteric / nematic phase shift liquid crystals.

Fig. 50 illustrates how the display of the liquid crystal display device 301 operates, and Fig. 51 is a graph showing the luminance – voltage characteristics of the liquid crystal display device 301. The liquid crystal display device 301 is a so–called normally–white–mode scattering liquid crystal display device, which is in the scattering state, and displaying bright, when no voltage is applied. The display operation of this liquid crystal display device is such that when no voltage is applied, that is, when the applied voltage is 0V, the liquid crystal display layer 305 is in the scattering mode, so that the incident light L1 is reflected to the front by the reflector 304, as shown in Fig. 50(a), and this reflected light is scattered. As the scattering is uniform with respect to all directions (isotropic scattering), it is indicated by the circle denoted by the numeral A1, which schematically represents the scattering state in the plane of Fig. 50. Here, it is assumed that the viewing direction M1 is different from the direction in which the emission light L2 (corresponding to the specularly reflected light) is emitted in the forward direction from the liquid crystal layer 305 when the liquid crystal layer 305 is in the transmitting state (see Fig. 50(d)). That is to say, the viewing conditions are assumed to be such that only specularly reflected light is avoided. Consequently, as viewing conditions for a liquid crystal

display screen, these viewing conditions are not at all unnatural.

Viewing from this viewing direction M1, a portion of the scattered light coincides with the viewing direction M1, whereby a bright display state is attained. Expressing the situation shown in Fig. 50(a) as luminance – voltage characteristics, the luminance is about 40%, as shown in Fig. 51.

Then, when the applied voltage is increased from 0V, the scattering state gradually decreases. As the scattering state decreases, the reflected light should converge in a certain direction, gradually diminishing the scattering range and leading to an elliptical scattering state as indicated by reference marker A2. Consequently, the amount of reflected light coinciding with the viewing direction M1 gradually increases. Then, when the applied voltage reaches Vp (= 2.5V), the amount of reflected light coinciding with the viewing direction M1 reaches a maximum, and the maximum luminance of 70% is achieved, as shown in Fig. 51.

Then, when the applied voltage exceeds Vp, the scattering range becomes even smaller, focusing in convergence direction (direction of the reflected light L2), and the reflected light gradually shifts away from the viewing direction M1. Therefore, as shown in Fig. 51, the luminance diminishes as the applied voltage is increased. Then, when the applied voltage is V1 (= 4V), the luminance drops to about 35%, which is lower than the initial luminance of 40% when no voltage is applied. Then, when the applied voltage is V2 (= 6.5V), the situation in Fig. 50(d) is attained, and the luminance becomes substantially 0%, as shown in Fig. 51.

The inventors have determined the luminance – voltage

characteristics of the liquid crystal display device 301 as shown in Fig. 51 under the following conditions:

cell thickness: 9μm

inclination angle θ1 of incident light: 30°

angle θ2 between viewing direction and normal on the substrate (viewing angle): 15°

Thus, it can be seen that the luminance I when no voltage is applied in the scattering–mode liquid crystal display device 301 increases as voltage is applied, until it reaches a peak value Ip (= 70), and then decreases, until it finally reaches about 0%. Consequently, in the liquid crystal display device 301 of this embodiment, the maximum luminance can be attained by setting the applied voltage to the voltage Vp at which the luminance is at the peak value Ip. Therefore, a brighter display that in the conventional examples can be attained by setting the driving range to the range between the voltage Vp corresponding to the maximum luminance and a voltage V2 where substantially the lowest luminance is reached (that is, a range of 2.5V to 6.5V in this embodiment), when driving the liquid crystal display device of the present embodiment. By driving in this driving range, there is no peak in the voltage – luminance characteristics, and gray-scale inversion can be prevented. It should be noted that the voltage V2 at which the luminance is lowest is not limited to 6.5V, and any voltage is suitable at which the luminance is substantially 0%. Also, in this embodiment, the display device is in a completely scattering state when no voltage is applied, but the present invention is not limited to this, and it is sufficient, if the liquid crystal

display device has an elliptical scattering intensity when no voltage is applied, that is at least closer to the complete scattering than the elliptical scattering state shown in Fig. 50(b).

Additional Remarks

(1) This embodiment has been described for a reflective liquid crystal display device, but the present invention can be equally applied to a transmissive liquid crystal display element.

(2) The present invention is also suitable for driving with a bias voltage, for example inversion driving, capacitive coupling driving, or FG (floating gate) driving.

(3) In addition, the present invention is also suitable for both active–matrix and simple matrix scattering–mode liquid crystal display elements.

The following is a more detailed explanation of these statements (1) to (3).

Embodiment C1

The following is a more specific explanation of Example C1.

Fig. 52 is a cross–sectional view of a polymer–dispersed liquid crystal display device 301A in accordance with Embodiment C1. The parts corresponding to the liquid crystal display device explained in the outline of Embodiment C are marked by the same reference numerals. In this liquid crystal display device 301A, a polymer–dispersed liquid crystal is used as the

scattering liquid crystal constituting the liquid crystal layer 305A. The liquid crystal display device 301A was manufactured with one of the regular methods. That is to say, a glass substrate (corresponding to the lower substrate 302) on a surface of which a reflector 304 was formed and a glass substrate (corresponding to the upper substrate 303) on the surface of which an ITO electrode is formed are laminated together with a sealing compound, thereby manufacturing an empty cell. Then, a mixed solution of liquid crystal and polymer (for example PNM201 by Dainippon Ink and Chemicals, Inc.) was introduced by vacuum injection into the cell. Then, UV light was irradiated for 60sec at an irradiation intensity of 20mW/cm^2, using a high–pressure mercury lamp, and polymerizing the polymer–dispersed liquid crystal material and phase–separating the liquid crystal and the polymer, a polymer–dispersed liquid crystal layer 305A was produced. The cell thickness was 9μm.

Then, the voltage – luminance characteristics of this liquid crystal display device 301A were measured with the parameters incidence angle θ1 : 30°, viewing angle θ2 : 15°, and a graph as shown in Fig. 51 was obtained. Consequently, it could be confirmed that by driving this polymer–dispersed liquid crystal display element 301A over the voltage range between from voltage Vp corresponding to the largest luminance to the voltage V2 corresponding to the lowest luminance (that is, the range 2.5V to 6.5V), a display that is brighter than that of the conventional examples becomes possible, and gray-scale inversion can be prevented.

To drive over this voltage range, it is possible to generate this voltage

range with a driving circuit outputting from 0V to the upper voltage limit, but it is also possible to use a driving circuit generating voltages with an appropriate difference between upper and lower voltage and a bias circuit generating the lower voltage. In this latter case, the absolute value of the voltages output by the driving circuit is low, so that transistors with a lower withstand voltage can be used for this driving circuit.

Embodiment C2

Fig. 53 is a cross–sectional view of a liquid crystal display device in accordance with Embodiment C2. This Embodiment C2 is an example of an active–matrix liquid crystal display device 301B for a color display. The main structural elements of this liquid crystal display device 301B are an active–matrix substrate 310 used for the lower substrate and thin–film transistors (TFTs) 311 made of amorphous silicon formed on this active–matrix substrate 310. An opposing substrate 313 is arranged in opposition to the active–matrix substrate 310, and an ITO electrode 312 is formed on the opposing substrate 313 as an opposing electrode. Furthermore, color filters 314 and a black matrix 315 are formed on the inner surface of this ITO electrode 312. In Fig. 53, numeral 316 denotes a reflective pixel electrode made of aluminum, for example.

If the bias voltage applied for inversion driving is set to the voltage Vp corresponding to the peak luminance of the luminance – voltage characteristics when performing inversion driving using this liquid crystal display device 301B, then the device is driven over the driving range shown

in Fig. 51, and the brightest display can be achieved. When the inventors performed inversion driving applying an actual bias voltage of about 2 to 3V, a display was attained, that was brighter than when no voltage is applied. Moreover, there was no gray-scale inversion when displaying intermediated gradations, and the display quality was superior. Here, "inversion driving" refers to a driving method, in which the potentials of the opposing electrode is varied.

By comparison, when display was performed with a bias voltage of 0V (regular driving), the display was darker than in Embodiment C2. Moreover, when displaying intermediate gradations, the gradation of white levels reversed, and the display quality deteriorated considerably. This seems to be due to the following reasons: If the bias voltage is set to 0V, then the luminance at an applied voltage of about 2 to 3V is higher than the brightness at these 0V, so that the white level is increased over the white level set on the basis of the luminance at 0V, and the gradation of white level reverses.

This example was explained for inversion driving, but it can be equally applied to FG (floating gate) driving applying a bias voltage (Journal of the Institute of Electronics, Information and Communication Engineers, 1991, 123, p. 47) or capacitive coupling driving (Flat Panel Display: 1993, p. 128).

Embodiment C3

The present invention is not limited to reflective liquid crystal

display devices, and can also be applied to transmissive liquid crystal display devices. As a specific configuration, it is possible to use a transparent electrode of, for example, ITO instead of the reflective pixel electrode 316 in Embodiment C2, and to provide a back light on the rear side of the substrate.

The voltage – luminance characteristics of this transmissive liquid crystal display device were measured with the parameters incidence angle θ1 of light incident from the back light: 30°, viewing angle θ2 : 15°, and a luminance – voltage graph similar to the one shown in Fig. 51 was obtained. As in Embodiment C2, a brighter display was obtained by applying a predetermined bias voltage. Moreover, when displaying intermediate gradations, gray-scale inversion did not occur.

Embodiment C4

The liquid crystal display according to Embodiment C4 is a so-called normally-black-mode scattering liquid crystal display device, which is in the transmitting state and displaying dark when no voltage is applied. The liquid crystal display according to Embodiment C4 was manufactured by the method described in JP H09-817630 using an active-matrix substrate. The cell thickness was 15μm.

When the luminance – voltage characteristics of a liquid crystal display device manufactured with this method were measured with the parameters incidence angle θ1 of incident light: 30° and viewing angle θ2 : 15°, the graph shown in Fig. 54, resembling a reversal of the graph shown in Fig. 51, was obtained. That is to say, the luminance – voltage

characteristics were such that the luminance was at a level of substantially zero from an applied voltage of 0V to a threshold voltage Vth (= 1.8V), and when the applied voltage exceeded this threshold voltage Vth, the luminance rose together with the applied voltage, reaching a peak value Ip (with a luminance level of 70%), whereafter the luminance dropped. The voltage Vp corresponding to the peak value Ip was 5V.

The following is an explanation of the reasons for the luminance – voltage characteristics shown in Fig. 54. In normally–black mode, the scattering situation is converse to that in normally–white mode, so that the scattering of the reflected light basically passes through the states Fig. 50(d) ➔ Fig. 50(c) ➔ Fig. 50(b) ➔ Fig. 50(a). Therefore, the graph shown in Fig. 54 is obtained as the luminance – voltage characteristics.

Thus, also in the case of normally–black mode, like in the case of normally–white mode, there is a peak value Ip in the luminance – voltage characteristics. Consequently, it is possible to attain a display that is brighter than in the conventional examples and to prevent gray-scale inversion by driving a liquid crystal display device in normally–white mode over a voltage range between the voltage Vp (= 5V) corresponding to the maximum luminance and the threshold voltage Vth (= 1.8V).

<u>Embodiment C5</u>

In Embodiment C5, the present invention was applied to a simple matrix liquid crystal display device using a simple matrix substrate. In this liquid crystal display device, if, when performing simple matrix driving

based on voltage averaging, the sum (VD + VS) of the scanning electrode voltage VD and the signal electrode voltage VS during the period when the scanning electrode is on (period when scanning line is selected) is set to a voltage corresponding to the above–described peak luminance, then it is possible to attain a display with sufficient brightness. The reason for that is that by setting the pixel electrode voltage (VD + VS) to a voltage corresponding to the above–described peak luminance, it becomes actually possible to drive over a voltage range (Vp to V2) in the voltage – luminance characteristics shown in Fig. 51.

For comparison, the inventors also performed pseudo–simple matrix driving based on voltage averaging using the liquid crystal display devices of the Embodiments C1 to C4. As a result, a sufficient display quality was also attained with pseudo–simple matrix driving. Moreover, a nice display was attained for up to 16 scanning lines. (It is possible to increase the number of scanning lines even further by steepening the gamma characteristics of the voltage – luminance characteristics.) Here, "pseudo–simple matrix driving" means that simple matrix substrates are not used for the substrate pair, but the driving is performed regarding it as simple matrix substrates.

Embodiment C6

Fig. 55 is a perspective view of a reflector used in a reflective liquid crystal display device according to Embodiment C6, and Fig. 56 is a cross–sectional view of Fig. 55. In this Embodiment C6, a "retroreflector" is

used for the reflector 320. Here, "retroreflector" means a reflector having the feature that incident light is reflected in a direction that is the same as this incidence direction. Using this reflector 320, an extremely strong reflection in the direction of the light source is attained. However, except under very unusual circumstances, the light source direction will not coincide with the viewing direction. That is because the viewer casts a shadow if the viewer is in the direction of the light source. Consequently, even when light is reflected back into the light source direction, there will be no problem in actual practice. Using such a reflector 320, the reflected light is deviated from the viewing direction, so that the viewing conditions of the luminance – voltage characteristics in the present invention can be satisfied. Consequently, it is possible to attain a display that is brighter than in the conventional examples and to prevent gray-scale inversion by driving the reflective liquid crystal display device of this Embodiment C6 over a voltage range between the voltage Vp at which the luminance is maximal and a voltage at which the luminance is minimal.

<u>Embodiment C7</u>

The following is an explanation of the temperature dependence of the luminance – voltage characteristics in a liquid crystal display device, and how it can be optimized.

When the temperature dependence of the luminance – voltage characteristics in the liquid crystal display device of Embodiment C1 (with a cell gap of 7μm) were measured, the graphs in Fig. 57 was obtained. Fig. 58

shows a graph, in which the voltages at which the luminance peaks are plotted against the temperature.

As becomes clear from these graphs, the voltage at which the luminance peaks shifts depending on the usage temperature. This temperature dependence of the luminance – voltage characteristics is due to for example the fact that the refractive index anisotropy Δn of the liquid crystal material is temperature–dependent. In order to attain a high luminance and a high contrast at various usage temperatures, it is preferable that the range of driving voltages is adjusted in accordance with the usage temperature. To do so, it is possible to adjust the upper and the lower limit of the driving voltage range. In particular for voltages on the high luminance side (that is, low voltages in Fig. 57) in the driving voltage range, the influence on maximum luminance and contrast and the occurrence gray-scale inversion is large, so that it is preferable to adjust the voltage at least on this high luminance side.

Such an adjustment can be performed manually, but it is also possible to provide a temperature sensor 333 near a display region 332 of the liquid crystal display device 331, as shown in Fig. 59, to pre–store data indicating the upper and lower limits of the driving voltage range in accordance with the output of the temperature sensor 333 in a memory 335 that is connected with the temperature sensor 333 over an A/D conversion circuit 334, and to let the driving circuit 336 output voltages over a driving voltage range based on the data that are read out from the memory 335.

As shown in Fig. 60, it is also possible to form a luminance detecting

region 342a near the display region 342 of the liquid crystal display device 341, and provide a photo–sensor 343 connected to an A/D conversion circuit 344 and detect the voltage at which the luminance peaks by scanning the driving voltage produced by the driving circuit 346 by appropriate control with a control circuit 345, and determine the bias voltage based on the detection result.

The detection of the voltage at which the luminance peaks can be performed at the time the device is turned on, but if its influence on the image display poses no problem, it also can be performed constantly or periodically during display. Also the temperature detection can be performed at the time the device is turned on, but if its influence on the image display poses no problem, it also can be performed constantly or periodically during display.

<u>Embodiment C8</u>

The temperature dependence of the luminance – voltage characteristics as explained in Embodiment C7 differs depending on such factors as the size of the cell gap or the particle diameter of the liquid crystal drops. More specifically, the temperature dependences of the luminance – voltage characteristics for cell gaps of 7μm, 12μm and 3μm are shown in Figs. 57, 61 and 62, respectively, and the peak luminance is greatest at about 20°C, 60°C and 0°C. It seems that the reason why the temperature at which the peak luminance varies is as follows: Usually, Δn is small at high temperatures and large at low temperatures, and consequently, the

scattering intensity is small at high temperatures and large at low temperatures. On the other hand, the range of scattering gains at which the peak luminance is high is determined, among others, by the size of the cell gap, and the peak luminance decreases when the scattering gain is larger or smaller than this region (optimum region). As a consequence, it seems that the luminance – voltage characteristics change depending on the usage temperature in this manner.

It is possible to display images with high luminance and high contrast by appropriately setting the size of the cell gap, the particle diameter of the liquid crystal drops, and the size of Δn at a certain temperature, so as to maximize the peak luminance at usage temperatures of, for example, 0 to 60°C, 10 to 40°C, or 20 to 30°C,

Furthermore, it is preferable that the temperature dependence of the Δn of the liquid crystal material is basically small. Here, Δn generally has the characteristic to rise sharply from the time that the liquid crystal material makes a phase shift from the high–temperature isotropic phase to the liquid crystal phase. Therefore, it is preferable that the phase shift temperature of the liquid crystal material is high, in order to reduce the influence of the temperature dependence of Δn in the usage temperatures range. As the result of in–depth research by the inventors, it was found that problems during usage do not occur if the phase shift temperature is at least about 15°C, preferably at least 20° higher than the upper limit of the usage temperature range. Furthermore, it was found that if the phase shift temperature is at least 80°C, then there are large limitations on the

materials, but on the other hand problems during usage do not occur.

Embodiment C9

There were cases when the luminance – voltage characteristics exhibited a plurality of luminance peaks, as shown in Fig. 63, when for example the substrate pair holding the liquid crystal layer was subjected to non–symmetrical surface processing. In such cases, gray-scale inversion does not occur and an image with superior gradation tones due to γ correction can be displayed easily if the voltage is driven over a driving voltage range from the voltage at the higher voltage luminance peak to the voltage at which the luminance is substantially zero, such that the luminance decreases monotonously.

INDUSTRIAL APPLICABILITY

As described above, the present invention presents a reflective polymer–dispersed liquid crystal display element in which high contrast and high luminance are attained without increasing the liquid crystal fraction, by regulating for example the scattering gain of the polymer–dispersed liquid crystal layer, the panel gap and Δnd.

Furthermore, by providing an anisotropic scattering means that scatters and emits light that is incident on the scattering display element anisotropically over a range of directions, an emission angle modification means that emits light such that the incidence angle is different from the emission angle, and an attenuation means for attenuating reflected light, the

luminance of the reflected light is decreased, and reflected light is emitted in a direction where it enters the visual field less easily, so that the influence of reflected external light, such as luminance inversion and loss of contrast can be eliminated, or at least reduced considerably, and luminance inversion, and reducing luminance inversion and gradation loss, it is possible to obtain a scattering display element with good visibility and high quality of the displayed image.

Furthermore, setting the driving conditions for the liquid crystal display element on the basis of the newly found luminance – voltage characteristics that exhibit a peak in the luminance level when changing the liquid crystal from the scattering state to the transmitting state, it is possible to obtain a reflective scattering liquid crystal display element with high luminance, high contrast and less possibility of gray-scale inversion.

Consequently, the present invention is useful in the field of devices having display elements, such as portable information terminals or portable gaming devices.